(2)

(14) DCIEM-TR-78X12

DCIEM TECH. REPORT 78X12

(6) THE [redacted] CANADIAN DIVING SYMPOSIUM (2nd)

HELD AT

DEFENCE AND CIVIL INSTITUTE OF ENVIRONMENTAL

MEDICINE,

31 OCTOBER - 1 NOVEMBER 1977.

(9) Technical rept.,

(10) D.J./Fullerton

(11) 1 Nov 77

(12) 145p.

78 07 31 1?9
406 986

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DEEP DIVING FACILITY UPDATE

By

D.J. Fullerton, P.Eng.

In response to the Defence White Paper in the 70's, Canadian Ocean Policy of 1973 and the impetus placed on the diving industry, DCIEM was given approval to proceed with the design and construction of the Deep Diving Facility in December, 1973. We were allocated a budget of 1.85 million dollars. In an effort to stay within this budget, it was necessary for us to assume the role of prime contractor, design team and fabricator of many components. With Mr. John Canty's engineering consulting expertise in pressure vessel design and advice in other areas beyond our experience, the assistance of DCIEM's human factors group and our own engineering expertise, the Deep Diving Facility is now becoming a reality.

The pressure vessels for the main chamber complex were received from Canadian Vickers 29 July, 1977 and set in their final position at DCIEM on 30 July. The vessels were somewhat late in arriving due to many unforeseen factors at Vickers relating to engineering and testing problems, for pressure vessels with such heavy walls. These were overcome however, and the vessels sucessfully passed the required tests for certification and code stamping.

DCIEM's responsibilities regarding design, fabrication and installation of supporting systems and sub-systems is on schedule and in some cases ahead of schedule.

As previously reported, the BIBS and helium storage banks are completely installed. The distribution system which receives chamber pressurization gases from the twelve pure gas banks and routes three of these to the control room for further selection are now completely installed. The transfer manifolds which receive the twelve pressurization gases and six BIBS gases and routes these to and from the equipment selection manifolds are also completely installed. The equipment manifold which receives the gases from the transfer manifold and subsequently routes the gases to and from the handling equipment, is completely installed.

The gas handling equipment we have purchased includes:

a. 0-3000 psig RIX helium compressors (30-50 scfm) - 2 only;

b. 3000-6000 psig Corblin diaphragm boosters (30 scfm) - 4 only;

c. 50 l/min vacuum pump;

d. Airco 3-gas mixmaker;

e. 5000 ft^3 helium storage bladder - 2 onl ;

f. 30-50 scf: International Crvgenic Engineering helium pre-purifier - 1 only;

All of the above items are now installed with the exception of the helium repurifier as it is in transit from the manufacturer now.

The equipment and manifold status board which graphically displays the gas routing through the system is now installed and operational. All gas manifolds, the display, and a gas sampling station have been enclosed in a control room dedicated to the control of gas processing and routing throughout the facility.

The instrument air system consisting of 1500 psi DCIEM supply air, a Bauer 7 scfm compressor, a Haskell booster, two 3000 psi storage flasks, a 125 psi accumulator and manifolds is now operational.

It is planned to begin training of DCIEM operators in the use of these systems early in 1978 to minimize the time lag between acceptance of the facility and the beginning of diving operations.

The oxygen system which is housed in a special explosion-proof room has been designed and installed. However, it has not yet been pressure tested or verified clean for oxygen service. The development of the other systems is also progressing satisfactorily.

The potable water system is now finalized and many components have been received. It will consist of 140 gallons of stored cold water maintained approximately 60 psig above chamber pressure by helium pressure. Hot water is manufactured as required by passing the cool water over a steam heat exchanger on its way to the shower or commode located in the sphere (entry lock). There will be an automatic shut-off when the water level gets too low for safe operation. At that time the storage will be replenished from city water supply lines. Installation is scheduled for late 1977.

The sanitary system is completely designed, and installation will begin shortly. A mechanical interlock mechanism on all valves in this system has been designed to eliminate the occurrence of any untimely accidents. The design of the water traps and equalization vents is presently being finalized. The toilet will be a pullman type fold down toilet and wash basin.

The design of the fire suppression system is completely designed and installation has begun. The system will be a water deluge type activated manually from inside the chamber or from a number of key external locations. We will not install an automatic activation system at this time as we are not convinced of its merit; however, should faster and more reliable systems become available in the future, we have the capability to retrofit them.

The wet pot cooling system has been designed in principle; however, some tests are planned to verify the design calculations for initial cooling of the water in the wet pot. This will be accomplished by vapourizing liquid nitrogen and bubbling it through the water. Once the desired temperature is attained it will be maintained by small internal heat exchangers inside the wet pot. We are re-evaluating this principle in terms of high operational costs and may decide to install a system utilizing more conventional cooling methods.

The heating system has been finalized and most components have been installed. Heating will be accomplished by external strip, pad, and heating cable fastened to key sections of the external chamber walls. The entire complex will then be covered with two inches of spray foam insulation. Temperature will be automatically controlled. This arrangement will facilitate very close control of the interior temperature due to the large heat source in the chamber walls. Also, there will not be any temperature stratification as witnessed in other installations as temperature is achieved by uniform radiation from the chamber walls rather than simply heating the gases introduced into the vessels.

We have received the environmental loop cannisters, designed the piping system, and have overcome the difficulty we were experiencing in obtaining suitable pumps for passing the chamber gases over these dessicant beds. We have been working with Nova Scotia Research Foundation (NSRF) and Undersea Equipment in the application of a suitable pump system developed by them to our specific needs. A viable solution has developed and a contract has been awarded to NSRF for the supply of these pumps.

The pressurization and depressurization systems have been designed and all components are on order. Pressurization is accomplished via remotely operated control valves from the control consoles. We anticipate maintaining dive rates of up to 150 ft/min. to approximately 3000 feet, after which, the rates will drop off slightly. Depth should be maintained within a few inches of the desired depth by a custom holding mechanism designed by our personnel. Also, decompression rates are controlled with the same accuracy from 1 ft/hr to 60 ft/hr automatically as desired. For faster rates, control is via remotely operated control valves from the console. We can maintain decompression rates of approximately 100 ft/min to about 30 feet. From 30 feet to the surface larger valves are utilized in an effort to maintain these rates. Our degree of success will be determined in our system trials.

The entire control room and its equipment is designed, received, and construction of the consoles is completed. Included in the control room will be:

1. compression/decompression controls

2. environmental monitors - PO_2; PCO_2; % R.H.; temp.

3. elapsed and 24-hour clocks

4. BIBS control and selection valves

5. pressurization gas selection valves

6. depth gauges

7. communication intercom and head-set interconnection computers

8. helium unscramblers

9. dictaphone voice actuated logging system

10. data acquisition and retrieval computer

11. closed-circuit television and videotape recorders

12. Airco mixmaker for emergency gas mixing

13. Canty light level controls

14. systems status board

15. fire system actuation controls.

It is planned that diving operations be controlled by four men. This is due mainly to very careful design of the controls and location of them, as well as full utilization of all automatic recording systems available to us.

It is important to note that there are manual controls for all automatic systems, and in the case of the oxygen systems, there are six mechanisms designed into the system by which we can control oxygen make-up.

The human factors design of the interior furnishings of the vessels has been completed as has the engineering design of the furnishings. The construction began once the chamber was installed as a considerable amount of extra fitting had to be done. The interior will be painted similarly to the full scale mock-up and all non-painted furniture will be stainless steel.

It is clear that the Deep Diving Facility is well on its way to becoming a fact. We anticipate that the basic installation will be completed approximately eight months after delivery of the chamber or sometime about March, 1978. By the fall of 1978 the system should be ready to conduct manned dives to approximately 3000 feet; however, our diving activities will be much shallower than this initially. Further excursions will only be possible after some critical components are modified such as our digital depth gauges which only have a capability of 100 bars or 3260 feet.

This brings up the point of the metric units that will be used in the operation of the system. Because Canada is already in the process of metric conversion, all displays and controls in the system are installed in metric units. Depth and pressure are both in units of bars, while partial pressures are in units of mmHg. These units were chosen because they are consistent with the SI system and other metricated diving nations.

Probably the most pressing question of importance to industry is the cost to utilize the DDF for private experimentation and research. In an effort to illustrate how these costs would be calculated the following example has been used:

PROJECTED OPERATING COSTS FOR CIVILIAN USAGE

1. HELIUM COSTS

A. Pressurization Costs

Assume:
- pressurization of entire chamber complex
- wet-pot is filled with water
- 25% of the helium handled is lost due to leaks, instruments, and reclaim system blowdown losses.

Calculations:

- volume of gas handled per foot of depth: 96.7 cubic feet
- losses: 96.7 x .25 = 24.2 cubic feet
- cost of helium: $0.08 per cubic foot
- cost of lost helium: approximately $2 per foot of depth — $2/foot

B. Pass-Thru Utilization Costs

Assume:
- each of 3 locks is cycled 3 times daily
- 25% of the helium handled is lost

Calculations:

- cost of gas handled per foot of depth per day in all lock operations: $.07 per foot per day For simplicity assume this cost is calculated on the average depth of the dive rather than the maximum or approximately 1/2 of the above cost: — $0.037/ft/day

2. OXYGEN COSTS

A. Pressurization Costs

Assume:
- 0.35 ATA oxygen partial pressure to be established.

Calculations:

- volume of oxygen required independent of depth: 560 cubic feet
- oxygen costs: \$0.035 per cubic foot
- cost of establishing atmosphere: approximately \$20 per dive — \$20/dive

B. Atmosphere Maintenance Costs

Assume:
- 0.35 ATA oxygen partial pressure to be maintained
- four divers within the chamber complex
- oxygen consumption per man per minute averages 1 litre.

Calculations:

- total daily consumption: 412 cubic feet
- oxygen costs: \$0.035 per cubic foot
- cost of maintaining an oxygen atmosphere: approx. \$15 per day — \$15/day

3. DESSICANT COSTS

A. Soda Lime

Assume:
- four divers within the chamber complex
- CO_2 production 1 litre per minute per man

Calculations:

- soda lime requirements per man: 20 pounds per day
- cost per pound: \$.70
- daily costs for soda lime: \$56 per day — \$56/day

B. Miscellaneous Dessicants

The following dessicants are used in small quantities or are regenerable. The quantities required are therefore estimated based on yearly requirements.

Assume:
- annual number of diving days is approximately 1/3 of the year or 130 days.

(1) Silica-gel

- approximately two 50 gallon drums (700 lbs) annually at \$1.00 per pound.
- Total annual cost: \$700

(2) Molecular Sieve

- approximately one 50 gallon drum (350 lbs) per year at $1.50 per pound
- Total annual cost: $525

(3) Charcoal

- approximately 80 pounds annually at $0.40 per pound
- Total annual cost: $32

(4) Purafil

- approximately 15 pounds annually: $43

The total annual cost of miscellaneous dessicants is $1300
The daily costs to recover this are: $10 per day — $10/day

4. LIQUID NITROGEN COSTS

Liquid nitrogen is used to chill the water in the wet-pot for cold water dives.

A. Initial Cool-Down Costs

- design calculations indicate that to cool the wet-pot from room temperature (21°C) to -2°C will require 22000 pounds of liquid nitrogen at $0.12 per pound: $2640/dive — $2640/dive

B. Low Temperature Maintenance Costs

- design calculations indicate that 960 pounds of liquid nitrogen will be required to maintain -2°C in the wet-pot every 24 hours at a cost of $0.12 per pound: $115/day — $115/day

5. COST OF MEALS

Assume:
- three 4-man watches per day to operate the complex.
- four divers within the complex. (Scientific support staff may increase this complement by 5 to 10 men).

Calculations:

- average cost for meals per man per day: $15
- total daily meal cost: $15 x 16 = $240 — $240/day

6. MISCELLANEOUS COSTS

Other costs may be incurred resulting directly from the cost of special equipment installations, scientific services, etc. as dictated by the particular experiment. These cannot be projected at this time, however, it may be safe to assume that these are absorbed by overhead charges.

7. OVERHEAD COSTS

Treasury Board policy dictates that an overhead charge of 65% of DCIEM's costs be added to total costs for non-military diving programs.

PROPOSED ACCOUNTING OF A TYPICAL 1000-FOOT DIVE

The following calculations are based on a civilian (industrial) dive of 1000 feet (445 psi) for 15 days (5 days bottom time, 10 days decompression), with the wet-pot chilled to -2°C for 5 days.

Operations and Maintenance Costs

a. Total of all daily costs x 15 days: $15 (oxygen) + $56 (soda lime) + $10 (misc. dessicants) + $240 (meals) x 15 = $321 x 15		$ 4,315
b. Cost of Oxygen Pressurization:		$ 20
c. Cost of Helium Pressurization: $2/foot x 1000		$ 2,000
d. Cost of Medical Lock Operation: $0.035/foot/day x 1000 x 15 days:		$ 525
e. Cost of Wet-Pot Cooling: $2640 + ($115/day x 5 days)		$ 3,215
	G & S Sub-Total	$10,575.00
	+ 65% Overhead	6,873.75
	G & S Total	$17,448.75

Personnel Costs

f. Operational personnel: $292 x 3 watches x 15 days		$13,140.00
g. Medical Officer: $200 x 15		$ 3,000.00
	Sub-Total	$16,140.00
	+ 65% Overhead	$10,491.00
	Personnel Total	$26,631.00

TOTAL COST OF 1000 FOOT/15 DAY SATURATION DIVE WITH 5 DAYS OF WET-POT COOLING.. $43,807.50

The non-recoverable costs for the dive 1977 dollars approximates $2920.50/day, or had it been conducted entirely under the auspices of DCIEM, the cost would be $705/day as overhead costs would not have been included.

When an information exchange is mutually agreed upon and the experimental data resulting from a civilian dive is of value to DCIEM, the dive costs will be shared as determined by the Chief, DCIEM.

As should now be evident, the DDF is well on its way to becoming a reality, and when completed, it will be one of the world's finest hyperbaric installations that the Canadian Diving Community can be proud to be associated with.

DCIEM DIVING AND RESEARCH PROGRAMME

1976 - 1977

By

LCDR B.A. Ridgewell

INTRODUCTION

This paper will be given in three parts. First I'll discuss the Diving Division's Organization and basically how it fits into the overall DCIEM organization. Secondly, I'll review our accomplishments since the first Canadian Diving Symposium at DCIEM in February, 1976, and finally, I'll discuss some of our future programs.

ORGANIZATION

DCIEM. Within DCIEM there are five research divisions, the School of Operational and Aerospace Medicine (SOAM), the Canadian Forces Central Medical Board (CMB) and of course, Administrative and Technical Division. The five research and operations division are:

a. Bio Sciences Division;

b. Behavioural Sciences Division;

c. Medical Life Support Division;

d. Health Sciences Division; and

e. Diving Division.

This organization chart is shown in Annex A.

Diving Division. The Diving Division is divided into four sections as shown in Annex B. These sections are:

a. Diving Operations Section;

b. Hyperbaric Facilities Section;

c. Diving Medical Section; and

d. Diving Research and Development Section

These sections vary considerably in size. The Diving Operations Section contains all the military clearance divers as well as a number of permanent staff civilian divers and hyperbaric chamber operators. The other sections are all small in numbers, however, they are well supported by the Operations Section and other divisions within DCIEM.

1977 ACCOMPLISHMENTS

The Diving Division as a whole has made good progress since the last meeting. Some of the accomplishments are as follows:

Saturation Dive - NEDU. In April, 1976 the Canadian Forces conducted their first saturation dive using the USN Navy Experimental Diving Unit's facilities in Panama City, Florida. A team of four clearance divers from DCIEM were saturated for eleven days to maximum pressure equivalent of 456 feet of sea water. The purpose of the dive was to evaluate surface supported diving equipment in water temperatures below 40°F. In addition to the equipment evaluation CF divers gained valuable saturation diving experience and our scientific personnel acquired extensive physiological and thermal stress data.

Operation Cold Diver III. Operation Cold Diver III was the third operational evaluation of the Commercial Diving Helmet Rat Hat and the Yokohama Diving Suit conducted in Bedford Basin, Halifax, Nova Scotia in April, 1977. Physiological and thermal monitoring of the CF divers was maintained throughout the evaluation which resulted in the accumulation of excellent data on cold deep water surface supported diving. The new CF hydraulic tool package was also evaluated during this operation.

Foreign Training. In September, 1977, Lt's(N) Fortin and Mitchell participated with French Navy divers on a deep training course at GISMER, France. This course consisted of four weeks of open sea diving using the French Navy MK 4 deep diving system to depths of 100 metres seawater.

DCIEM Training. Thirty-five weeks of training are conducted by the Diving Division in co-operation with the School of Operational and Aerospace Medicine at DCIEM. The majority of these courses are in support of the Maritime Commander and the Surgeon General. There are, however, a number of courses which are conducted in support of other government departments such as MOT, RCMP and OPP.

Research and Development. Our major contribution to Diving Research and Development has been in the decompression computer field. A new production model electronic decompression computer has been produced by Canadian Thin Films (CTF) Ltd. of Port Coquitlam, British Columbia. These computers were developed at DCIEM and CTF were contracted to build two models, the XDC-1 (electronic decompression calculator) and the XDC-2 (electronic decompression monitor). Initial testing of these computers indicates that these new electronic models have eliminated all the problems we have experienced with our older pneumatic decompression models. If the results of our evaluations are successful, it is intended to recall all the operational pneumatic decompression computers currently in use and issue the new XDC-2 computers for use with hyperbaric facilities and surface supported diving systems of the Canadian Forces.

Test and Evaluation. The major effort in test and evaluation has been directed towards building a breathing machine which will simulate a diver breathing at various work rates, water temperatures and depths of water. It is now possible to quickly test all diver life support equipment in the unmanned mode to pressures equivalent to 1000 feet of seawater. The first major evaluation using this apparatus was a single hose regulator evaluation which compared various off-the-shelf breathing regulators measuring inhalation and exhalation breathing resistances. As a result of this objective evaluation and subsequent subjective evaluation, a new single hose regulator will be introduced into the Canadian Forces in 1978. The breathing simulator and the 1000 fsw test chamber are routinely used to test diving equipment that has been involved in diving accidents or incidents. Accident investigation is becoming an ever increasing commitment to the Diving Division.

Hyperbaric Facilities. The hyperbaric facilities of DCIEM include a 1000 fsw unmanned test chamber, a 340 fsw training/treatment, and recompression chamber (RCC) and the new 5600 fsw saturation Deep Diving Facility (DDF). The major effort has been in the construction of the DDF. The main pressure vessels were placed in the building on 29 July, 1977, and since then the emphasis has been to assemble the consoles and associated equipment in the main control room. This now is nearing completion leaving only the plumbing of the main chamber and life support loops left to finish. In addition to the DDF five air and helium/oxygen diving consoles have been designed and built by the Diving Division for use by the Fleet Diving Units, CF Diving Tenders and the new diving support ship HMCS CORMORANT.

FUTURE PROGRAMS

DDF. The first priority of the Division is for the DDF to be operational by the fall of 1978. A one atmosphere dive is planned for summer. This is an unpressurized 10-day dive to evaluate the human engineering design of the DDF and identify interface equipment problems. Commencing early in the new year various sub system testing will be conducted resulting in complete systems tests by early summer. The wet chamber will be ready for equipment pressure tests by 1 May, 1978.

Projects. There will be five major projects within the Diving Division next year. These projects encompass all types of diving done by the Canadian Forces and are divided into the following categories:

a. Self Contained Underwater Breathing Apparatus (SCUBA);

b. Surface Support Diving Systems (SSDS-HARDHAT);

c. Submersible Diver Lockout (SDL-1);

d. Mine Counter Measures Breathing Apparatus (MCMBA); and

e. Hyperbaric Facilities Equipment (HFE).

Some specific areas of unique development which will effect a number of the above projects are:

a. SCUBA electronic decompression computers;

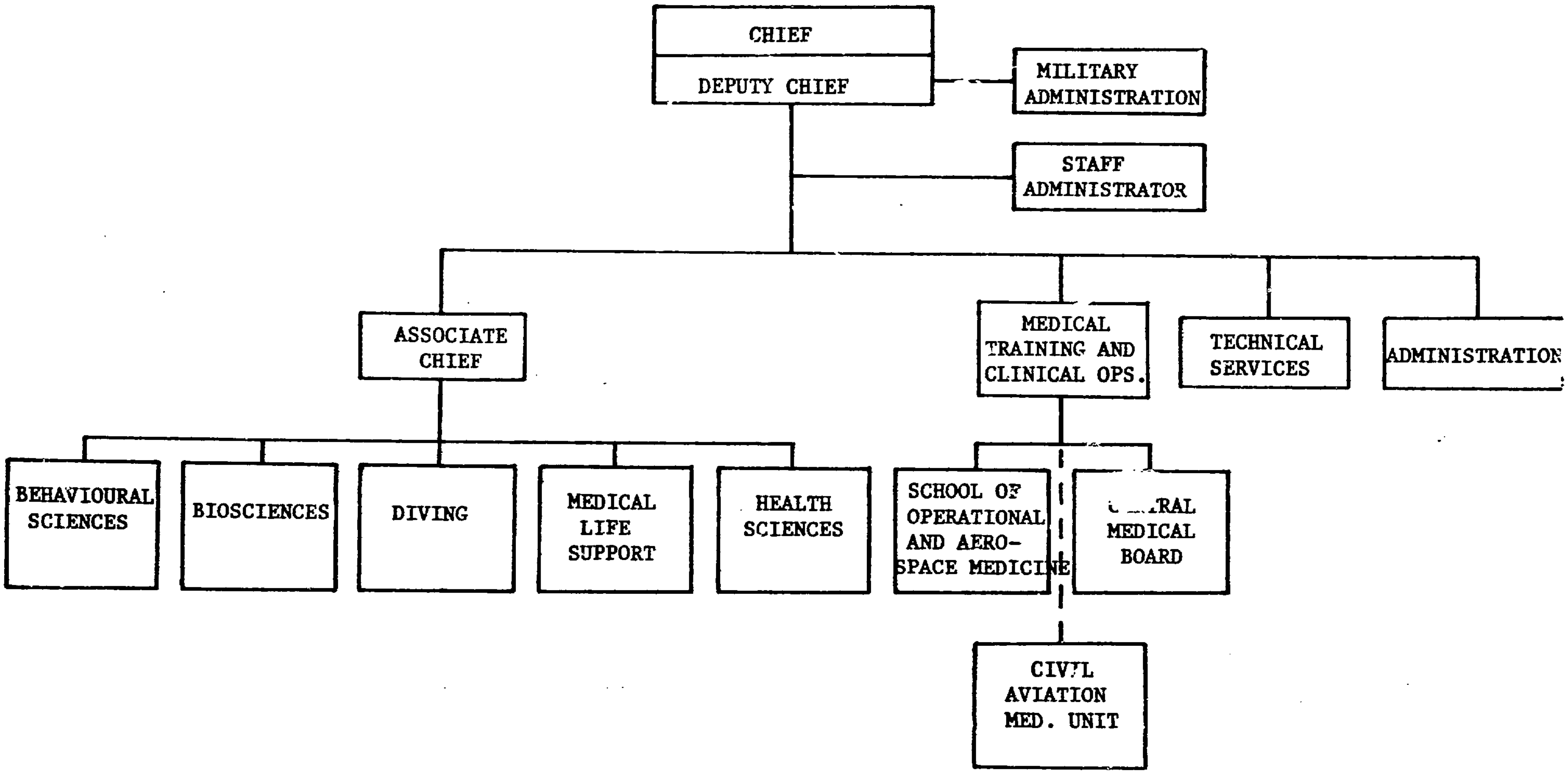
b. a new reservoir concept to stow medium pressure air/gas mix; and

c. an improved passive thermal protection suit for divers.

CONCLUSIONS

I have explained an organization, reviewed our recent accomplishments and discussed our future programs. I think you will agree that our diving programs are in accord with our mission which is to enhance human effectiveness in the hyperbaric environment.

The Diving Division is a small group of approximately twenty-three people who in my opinion, have achieved a great deal to improve the effectiveness of man-in-the-water. Thank you.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HEALTH SCIENCES
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MEDICAL BOARD
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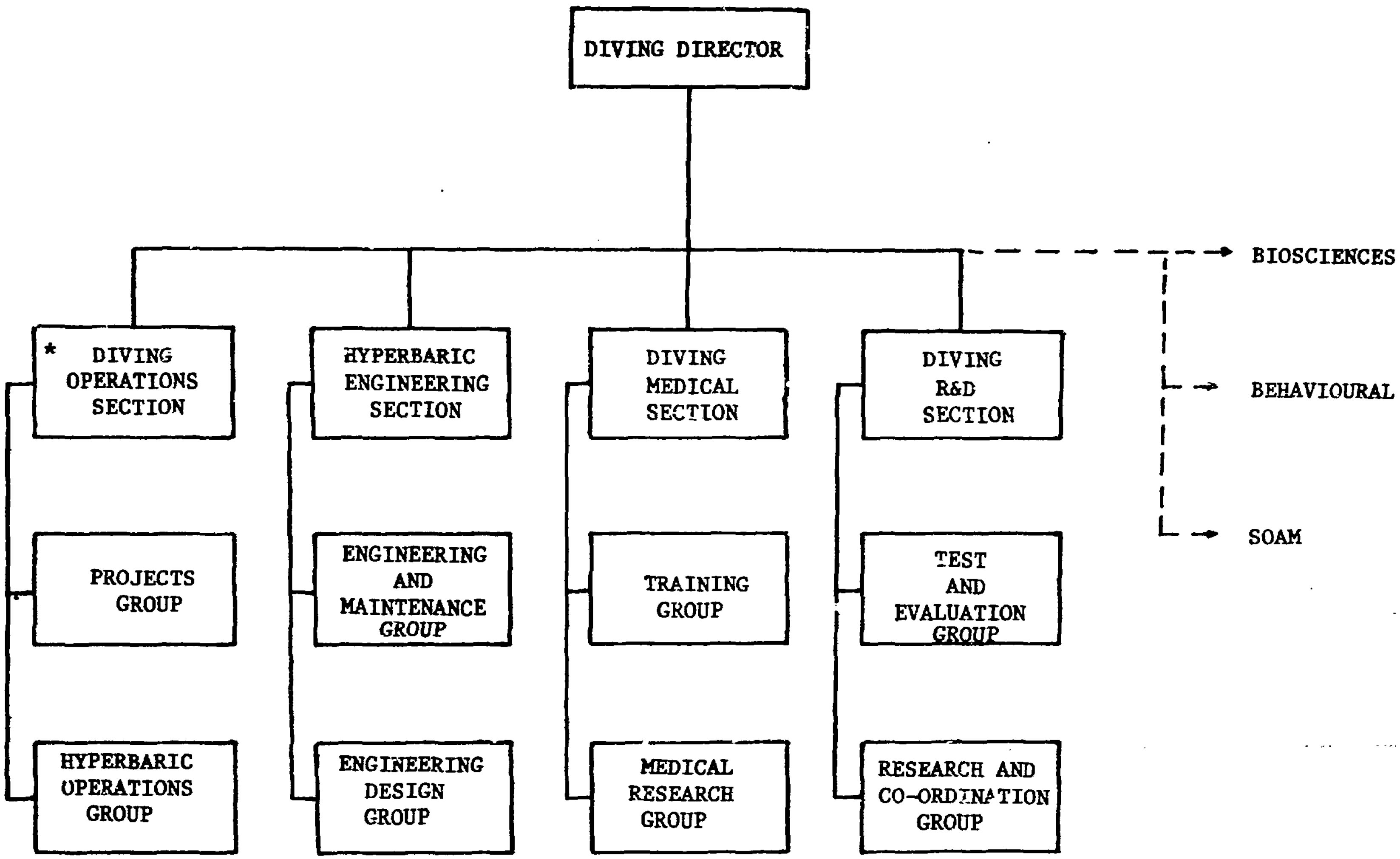

* Deputy Division Director

SAFETY EXPOSURE LIMITS
FOR DIVERS IN COLD WATER

By

Dr. L.A. Kuehn

ABSTRACT

Hypothermia is now one of the major factors affecting diver safety, performance and comfort in operational diving in cold water. This paper presents a brief overview of the physiology involved in human heat exchange and the consequential physiological events to heating or cooling. Thermal exposure limits which can be easily implemented in laboratory environments are presented as well as rough and ready generalizations which are applicable to field emergency situations. The use of cheap disposable temperature-radio pills in conjunction with portable battery-powered hand-held temperature-radio receivers is recommended for application to the working environment to monitor diver core temperature on the surface (or in a bell) before and after dives.

INTRODUCTION

The human body has developed through evolution a thermoregulatory system primarily adapted to semi-tropical and temperate environments (1). As with all homeothermic mammals, the human body has a deep internal temperature of approximately 37°C. The fact that this temperature is fairly constant and set at this particular value is that greater efficiency of the body's complex biochemical systems occurs at a uniform thermal state characterized by a constant temperature, optimally 37°C (2).

The whole of the human body is not maintained at this particular temperature; only the most central and vital body organs possess temperatures near 37°C. These organs, the brain, heart, lungs, liver and upper digestive tract, are considered to be the "core" of the body. The core organs are maintained at temperatures between 36 and 38°C for adequate functioning. The rest of the body, comprised of muscular and skeletal systems, fat reserves, and skin, does not depend on stable or uniform temperature for optimal physiological performance. These parts of the body can be considered as a "shell" surrounding the vulnerable core, serving to buffer and protect it from adverse heat transfer in thermally stressful environments. The average or mean temperature of the shell primarily depends on the thermal demand of the environment.

It must be realized that the shell is a conjectural and not a anatomical entity. It is not fixed in magnitude, structure or thickness. Indeed, the distinction between the innermost edge of the shell and outermost edge of the core is at best tenuous. Even within the homeothermic core, small differences in temperature exist from organ to organ, fluctuating with metabolic activity and following a continuous diurnal variation (4,5).

Though the shell-core concept of the body is crude and simplistic, it has been applied with success to complex physiological problems. In cold environments, the shell is thermally sacrificed such that the flow of warm blood into it from the core is greatly reduced by means of vasoconstriction. As a consequence, the net internal convective heat transfer of the shell tissues is decreased and an effective increase in thermal insulation occurs, whereby heat is lost primarily by conduction through the shell. This net conservation of heat is also effected by an efficient countercurrent heat exchange process between the arteries and veins of the limbs (6). In very cold environments, the temperature of the limbs can decrease to that of the ambient environment, causing severe cold injury if this temperature is below the freezing point of water.

In warm environments, the blood flow from the core to the shell is increased by complete opening of the surface blood vessels (known as vasodilation) in an attempt to reduce the heat content of the core. Transfer of heat through the shell is then expedited by perfusion of the blood as well as conduction through the tissues. The thermal insulation of the shell is minimal and the countercurrent heat exchange system non-functional.

The chemical energy inherent in food is converted into the biochemical energy stored within the body, a process called metabolism. Although this biochemical energy serves to provide mechanical energy for work, this conversion is an inefficient process and much of the potential energy is converted to heat, which is used to maintain the constancy of body core temperature in all homeotherms. Depending on the thermal state of the environment, the body may either gain or lose heat, but in environments in which thermoregulation is possible, the balance of energies is such that

$$\begin{matrix}\text{Metabolic Energy} \\ \text{Production}\end{matrix} - \begin{matrix}\text{Muscular Work} \\ \text{Completed}\end{matrix} + \begin{matrix}\text{Environmental} \\ \text{Heat Gain}\end{matrix} = \begin{matrix}\text{Environmental} \\ \text{Heat Loss}\end{matrix}$$

The heat produced as a result of bodily activity can vary greatly from the "basal" metabolic rate inherent in sleep, to the values required for the most strenuous of brief human activities, such as the lifting of heavy weights. Even moderate activity of the body requires continuous dissipation of large quantities of heat. Usually, the environment of man is such that it is a heat sink for heat coming from the body, thereby facilitating metabolic heat dissipation. If the heat transfer to the environment is excessive, the body can be

forced into heat debt with resulting drop of body temperature and danger of hypothermic injury. On the other hand, in certain environments, the ambient conditions are such as to encourage heat gain by the body, thereby causing considerable thermal strain on the core and resulting in increasing core temperature. The transfer of heat to or from the body proceeds according to well established thermophysical laws. In environments in which the atmosphere is not saturated with water vapour, it is possible to transfer heat from the body via the evaporation of sweat from the body surface. This heat transfer requires no thermal gradient but it does require a water vapour gradient near the skin.

The generalized equation for heat exchange and balance of the human body with its surrounding environment can be written as:

$$S = M - (R + C + K) - V - E$$

where M = metabolic heat production as a result of body activity or work,
R = radiative heat transfer or radiation,
C = fluid convection heat transfer,
K = conductive heat transfer or conduction,
V = respiratory heat transfer,
E = evaporative heat loss,
and S = storage of heat in the body.

The values of R, C, K and V can be positive or negative denoting that heat transfer is possible to or from the body via these routes. Evaporative heat transfer always represents a cooling of the body or net heat loss. The storage term S can also be positive or negative as in the case of heat stress or gain and cold stress or heat loss respectively. If this term has a zero value, then thermoregulation of the body is accomplished and the body core temperature remains constant.

This equation illustrates the major factors in thermoregulation. Metabolic heat production and the cooling power of the atmosphere have to be so manipulated by the temperature-regulating systems of the body as to yield a value for S of zero. In human terms, V is usually negligible. In many environments for man at rest, sweating is not necessary and the problem is one of heat conservation. Temperature regulation under such circumstances depends upon the control of R, C and K - which is largely a matter of skin blood flow control. In exercise, even in cool environments, R, C and K may not be sufficient for control. In hot environments, R, C and K may be negative items. Under such conditions, E, evaporative heat loss, becomes the sole means of maintaining thermal equilibrium.

DIVER HYPOTHERMIA

The major thermal problem faced by working divers is that of progressive hypothermia, starting with the limbs and body regions most poorly perfused or distant from the core. The principle avenues of heat loss for immersed divers are convection, which is relatively constant in magnitude for all depths, and respiration heat loss, which increases with depth of the diver and becomes the major avenue of heat loss for depths greater than 600 feet. No diving suit technology, with the exception of the surface-supported or bell-supported hot water systems, have been developed which can adequately protect the diver against eventual hypothermia in cold water.

Figure 1 shows the response of human body temperatures during cold water immersion (9) against a generalized time axis; alongside the response curve are indicated the various physiological signs and symptoms encountered at various body temperatures. Immediately after immersion of a passively-suited diver in cold water, there is an initial period during which the body attempts to maintain thermal balance by heightened activity and greater oxygen intake, but in most cases the rate of heat loss exceeds the heat produced by this extra metabolic activity. As the heat loss continues, the body becomes hypothermic and its physiological functions show an exponential decline with decreasing body temperature (10).

As hypothermia develops, shivering begins and reaches a maximum when the diver is at a core temperature of 35°C (11). At lower body temperatures, it gradually disappears to be replaced by overall body rigidity when the core temperature is in the region of 33-30°C (12). This rigidity itself disappears at a lower core temperature of 27°C and is replaced by a general muscle looseness or flaccidity.

Mental function becomes quickly impaired with hypothermia, usually noticeable at a core temperature of 34°C. At this point the state of the individual is semi-consciousness, characterized by confusion, disorientation, introversion (and upon recovery, amnesia). Consciousness and tendon reflexes are lost at a core temperature of 29-31°C (11).

During the cooling process (after the initial stimulatory phase of activity on immersion) the heart rate declines and a marked peripheral vasoconstriction occurs. The heart rate continues to decrease with increased heat loss and cardiac arrhythmias occur at a core temperature of 33°C. Eventually, ventricular fibrillation sets in at a temperature of 28°C, at which point death by hypothermia can be said to occur.

DIVER HYPERTHERMIA

In certain specific diving environments hyperthermia or "heating" of the diver is as much or more of a danger than is hypothermia. These environments include saturation chambers, diving bells and surface-supplied hot water suits. Such considerations have only recently been recognized as potentially hazardous to life.

As heat stress is incurred by a diver, all vasoconstriction of his surface blood vessels disappears and he is said to be in a state of vasodilation with maximum transfer of body heat from the core to the surface. Such a condition can usually be perceived as a "flushed" or reddened state. Although in nearly all temperate environments there is a transfer of heat by evaporation from the surface of the body due to water diffusion through the skin (called insensible perspiration), active perspiration occurs as the pouring of sweat on the surface of the skin by sweat glands to produce a maximally wet area for evaporation cooling. This is the body's main defence against heat stress. The onset of sweating is thought to be controlled by sympathetic innervation, deep skin receptors or the hypothalamus in the brain. There is no advantage to increased production of sweat once it begins to drop off the body because all evaporative benefit is thereby lost. Eventually with increased sweat loss and heat stress the body is depleted of water for evaporation and sweat no longer is produced. At this point, diver core temperature increases markedly and heat collapse (and heat death) is imminent.

THERMAL EXPOSURE LIMITS

To protect a diver against the dangers implicit in hypothermia and hyperthermia, limits to water immersion (or hyperbaric) exposure can be set such that if the diver activity is regulated within these limits the chances of hazardous heat or cold stress are minimized.

Five concurrent conditions (13) to protect against adverse diver hypothermia are:

1. The maximum net loss in the exposure should be less than 200 Kcal (for an 81 kg male).

2. The core temperature (as measured by rectal, aural, esophogeal or radio pill techniques) should not be lower than 36°C.

3. The mean skin temperature (comprized of at least four distinct skin temperature measurements) should not decrease below 25°C; furthermore, no individual skin temperature should be less than 20°C except the hand, which may go as low as 15°C.

4. The metabolic cost of shivering should be no more than that required to increase the oxygen consumption rate 0.5 l/min above the cost of the diver's activity.

5. The minimum inspired gas temperatures as a function of depth should be as specified in Figure 2 (14).

In the application of heat to a man, either as supplemental heating in cold water or during rewarming of a previously chilled diver the following limits apply.

1. The core temperature should be maintained less than 38.5°C.

2. Mean and individual skin temperatures should be less than 42°C.

3. The maximum inspired gas temperature should be less than 45°C for a one-hour exposure and 40°C for indefinitely long exposures.

It is recognized that these thermal limits are easiest to apply to cold water divers in laboratory situations and are difficult if not impossible to apply in operational open-water environments. There are certain warning signs or indicators which can be used to "flag" or identify an impending thermal crisis.

In potentially hypothermic conditions, coldness of the skin to the point of pain is a sign that the body is rapidly losing heat. Obviously, intense uncomfortable shivering is another warning that the body is becoming hypothermic and is endeavouring to warm itself by the metabolic benefit associated with massive shaking of the large muscle groups. If either of these signs is not apparent to monitors of the diving activity due to diver ignorance or unwillingness to properly inform his tenders of his state, then confusion and irrationality in the diver's verbal communication may reveal his plight. Collapse or unconsciousness of the diver should lead to an immediate suspicion of diver hypothermia, for which proper diver rewarming techniques should be deployed.

It is important to realize that most working divers expect their diving exposures to be cold and have a tendency not to complain unduly about their lot. They should be encouraged to divulge their true thermal perception to their tenders throughout cold working dives, especially if intense surface pain or shivering are present.

Until recently diver hyperthermia was a rare occurrence although the experience of heat stress is one that encourages personnel to complain loudly of discomfort. Nevertheless, there are certain physiological signs that can be used to identify a potentially hyperthermic victim. Flushed, reddened skin, especially in combination with profuse sweating are the classical symptoms of heat strain. Others are postures maximizing body surface area and attempts at removal of clothing.

PRACTICAL DIVER THERMAL MONITORING

It should be clear that the thermal limits proposed in the preceding section do not lend themselves easily to diver monitoring in the field and, furthermore, that the warning signs of impending diver collapse from heat or cold stress are useful only in extreme situations. There is a need for inexpensive reliable rugged and simple instrumentation for routine monitoring of all divers in cold water exposures.

The device that most readily lends itself to such application is the disposable temperature-radio pill. This technology has been in existence for over two decades (15) but, until recently, construction techniques caused such pills to be very expensive and necessitated that they be recovered for reuse. Such a constraint caused them to become unpopular in diving circles. Furthermore, the monitoring technology was always rather cumbersome and difficult to use quickly and routinely.

Recent developments at DCIEM (16, 17, 18) have led to the development of a throwaway temperature-radio pill in a shallowable capsule which emits a radio signal that varies with the temperature to which the pill is exposed over a range of approximately three feet. A separate hand-held radio pill readout device has been developed which, although it cannot measure continuous temperature readings when the diver is immersed, can be used to determine easily the diver's core temperature before and immediately after diving. The device is held close to the diver's abdomen and the indicated temperature is displayed on a small analogue meter. In this way, the thermal cost of the diving mission can be quickly assessed.

The individual pills can be calibrated with a water bath to obtain the proper calibration setting for the readout unit. In practice, this is not usually necessary if it is assumed that the diver's starting temperature, before donning his suit, is 37°C. If this assumption is made, the hand-held unit is then adjusted until 37°C is indicated on the pre-dive readings.

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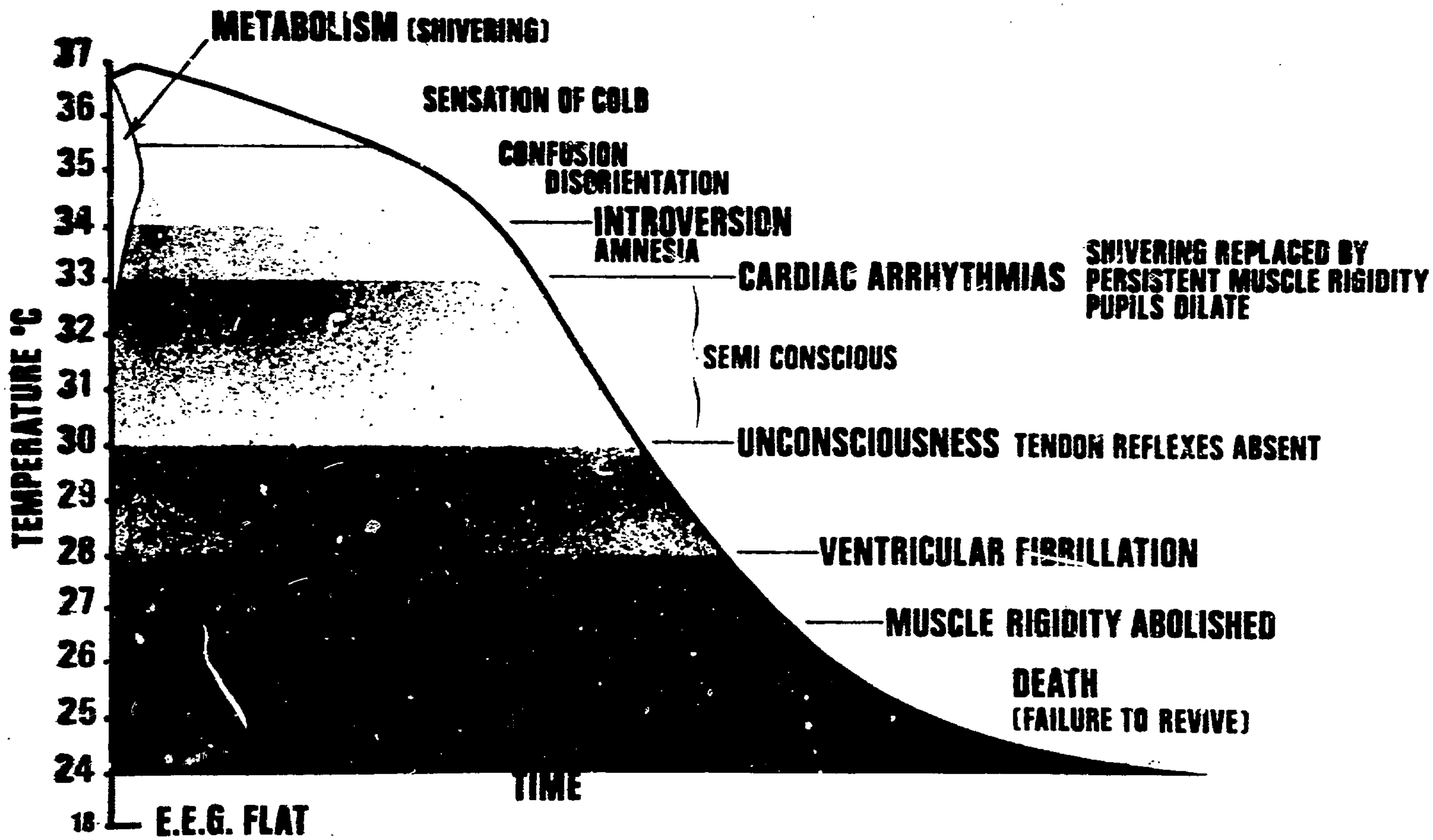
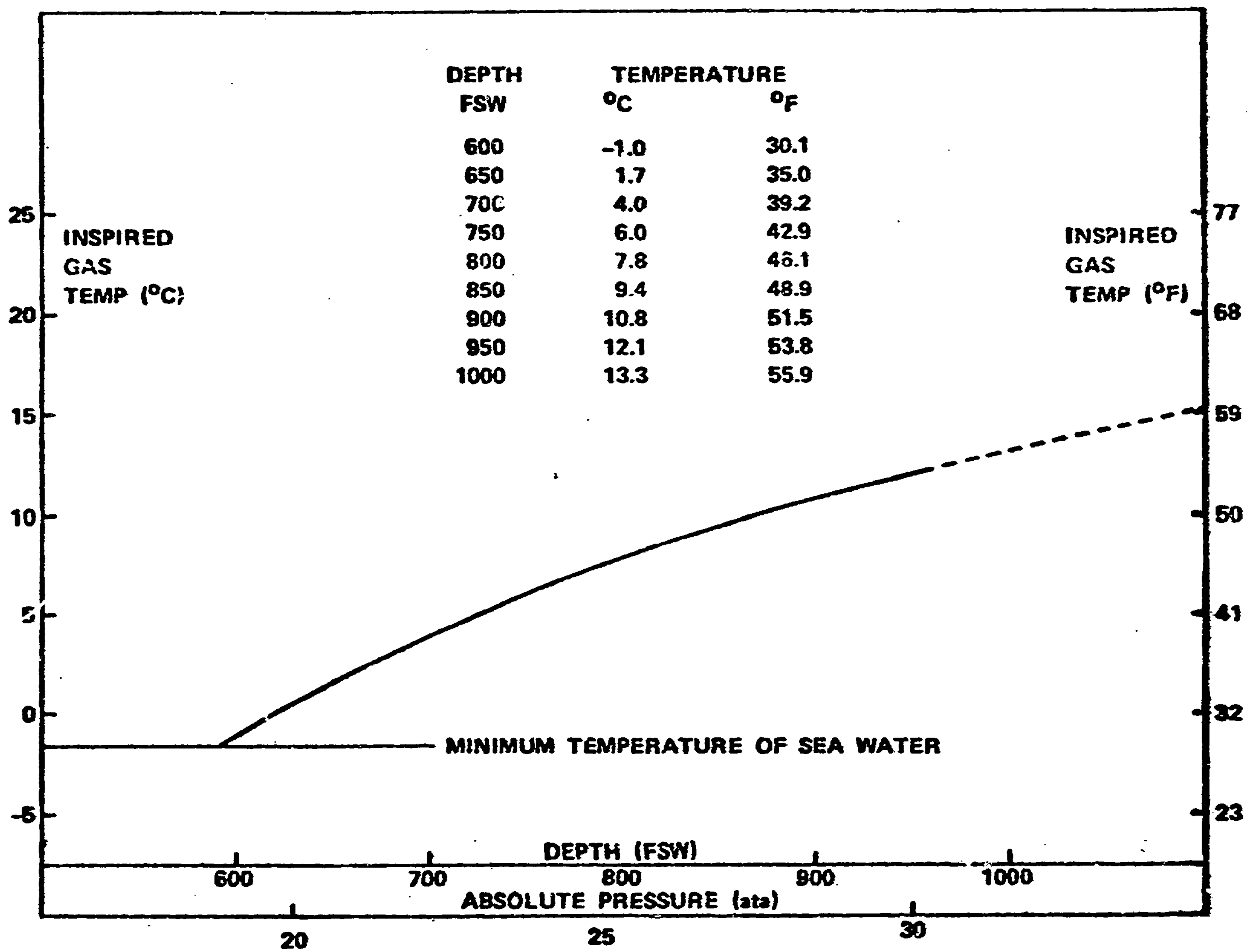
SYMPTOMS AND SIGNS IN ACUTE HYPOTHERMIA





DEPTH FSW	TEMPERATURE °C	°F
600	-1.0	30.1
650	1.7	35.0
70C	4.0	39.2
750	6.0	42.9
800	7.8	46.1
850	9.4	48.9
900	10.8	51.5
950	12.1	53.8
1000	13.3	55.9

FIGURE CAPTIONS

1. Portrayal of physiological events associated with general human hypothermia against a generalized time axis (taken from Reference 9: Golden, F., Recognition and Treatment of Immersion Hypothermia, Proc. Roy. Soc. Med., 66, 1058-1061, 1973).

2. Recommended minimum respiratory temperatures in cold water diving (taken from Reference 14: Braithwaite, W., The Calculation of Minimum Safe Inspired Gas Temperature Limits for Deep Diving, EDU Report 12-72, United States Navy Experimental Diving Unit, 1972).

PASSIVE RESPIRATORY HEAT RECLAMATION FROM DIVERS

J. Kotlarz, L. Pogorski and L. Kuehn

INTRODUCTION

One of the major avenues of diver heat loss is through respiration of cold breathing gas; it becomes the primary avenue of heat loss at moderate or greater depths and is important even in surface or SCUBA exposures. To protect a diver against this potentially hazardous problem a new device was designed specifically for passive respiratory heat reclamation, thereby minimizing energy cost and discomfort to the diver.

The history of respiratory heat reclamation and subsequent warming of inhaled gas dates back at least 35 years. The first patent (2,269,461) dated January 13, 1942 was entitled, "The Lehmberg Respirator". Since that time many gas conditioning objectives have been proposed. Generally, the development trend of the breathing apparatus was from a land to an underwater application. Unfortunately, the land designs were much too complicated in a typical water environment and, furthermore, were inadequate when considering corrosion and pressure problems. To date, many of these problems have been either solved or improved, consequently resulting in novel designs of heat reclamator devices. In order to achieve and improve upon a number of desirable exchanger objectives, a particular design was achieved by co-inventors, Kuehn (DCIEM) and Pogorski (Chemical Projects Ltd.). This design stresses non-hygroscopic material and consists of a composite conductor/non-conductor disc packing contained in a polyvinylchloride (PVC) shell (Figure 1). This paper is the result of more than 160 tests for different conditions and prototype exchangers.

THEORY

Respiratory heat loss takes the form of both sensible and latent heat. Sensible heat is a function of the density and heat capacity of the breathing gas and the difference between exhaled and inhaled temperatures. Normally, the breathing gas is dry and colder than the exhaled breath. Latent heat on the other hand is a function of breathing gas density, heat of vaporization and the differences in humidity ratios between exhaled and inhaled gas. The efficiency at which a heat reclamator can capture this available heat is a function

of the following:

$$E(\%) = \frac{C_c\,(T_{in} - T_g)}{C_{min}(T_{ex} - T_g)} \times 100$$

where,

C_c is the heat capacity of the cold breathing gas,

C_{min} is the minimum heat capacity of the gas and,

T_{in}, T_{ex}, T_g - respectively - inhale, exhale and gas temperatures.

For the temperature range 0^o to 30^o Centigrade, C_c is approximately equivalent to C_{min} so that efficiency becomes a function of temperature only. Indirectly, however, the efficiency depends upon the exchanger material and physical properties. Combinations of these properties are infinite in number and their optimization with respect to certain design objectives becomes critical.

The final theoretical evaluation of a heat reclamator is depicted by a temperature profile. Figure 2 (particular to the Kuehn/Pogorski design) shows a series conductor/non-conductor heat transfer as a function of the amount of heat transferred over the area "A" and the conductive and convective heat transfer coefficients. Heat is dissipated radially on the conductive discs and is then promoted laterally across the non-conductors over the length of the exchanger.

OBJECTIVES AND DESIGN

The following is a list of desirable heat reclamator objectives to be optimized:

a. Efficiency,

b. Economy,

c. Compactness,

d. Corrosion Resistance,

e. Low Maintenance,

f. Low Pressure Drop,

g. Non-hygroscopic,

h. Operability 1-30^{o}C/1000 feet,

i. Minimum Dead Volume,

j. Simple Design,

k. CAF Compatibility.

Several prototypes were developed, tested and studied for practical application to operational diving. These prototypes have a high thermal efficiency and are all composed of composite disc packing. In order to conduct a meaningful study on the effects of different packings, the following prototypes herein referred to by number were designed:

Heat Reclamator (HR)	1 -	2in x 2 in PVC Shell 27 Brass Discs/Mesh 50 27 Plastic Discs/Mesh 24
HR	2 -	2 in x 4 in PVC Shell 130 Brass Discs/Mesh 50
HR	3 -	2 in x 4 in Nylon Shell 110 Copper Discs/Mesh 100 110 Plastic Discs/Mesh 24

TEST EQUIPMENT-OUTPUT

A multiplex output for a normal respiratory cycle was obtained by placing thermistors at both ends of the exchanger. These thermistors were connected to a constant current supply, an amplifier, a log-amplifier and finally, a multiplex recorder. Sequentially timed recordings of the mouthpiece and gas inlet thermistors were obtained to give cyclical patterns as shown in Figure 3.

The plateau reached during the exhale cycle for the mouthpiece thermistor represents near-body temperature. The inhale plateau corresponds to the gas inlet temperature. The work performed by the reclamator in capturing heat is evidenced by the temperature profile between the two thermistors.

RESULTS AND DISCUSSION

Figure 4 shows theoretical plots of efficiency as a function of gas inlet temperature for different inhale temperatures. It serves only as a guide to predicting behaviour as a function of temperature only. Experimental plots were obtained by using different breathing gas mixtures and reclamators.

A. Heat Reclamator 1 (see attached Figures 5 and 6)

Figure 5 correlates experimental and theorteical results for a helium-oxygen (80/20) mixture. At moderate temperatures (9° to 20°C), the correlation is good, however, for low temperatures (less than 9°C) and high temperatures (greater than 20°C) positive deviation of experimental results occurs, a situation favourable to the use of the exchanger in diving. The standard test for other exchangers already on the market at T_g = 1°C shows that they are approximately 12% less efficient than this design.

Unfortunately, due to the inherent hygroscopic effects at the defined low and high temperatures, the resistance to breathing becomes critical. To reduce the resistance parameter, the exchanger material was dried, thereby resulting in an 8% efficiency decrease (78% at 1°C - Figure 6).

Due to continued use of the reclamator, the collection of latent heat (hygroscopic effect) caused an increase in efficiency from 82% to 94%. The associated resistance to breathing due to water collection in the exchanger increased the difference between exhaled and inhaled gas temperatures across the exchanger decreased substantially. The high pressure drop experienced across the length of the exchanger in sustained usage was undesirable and irksome to the subjects.

Plots for air and 100% oxygen respectively are comparatively summarized in Figure 6. It is interesting to note the particular shapes of the efficiency plots for different gases. Although heliox does not seem to have a maximum efficiency for a decrease in gas inlet temperature, air does at around 6°C. Furthermore, 100% oxygen has a constant efficiency profile.

It is noteworthy to point out the value of these graphs, namely, that given an ambient temperature and a heat reclamator, there is a corresponding optimum gas which may be used by the diver.

B. Heat Reclamator Comparisons

A comparison of reclamators for a given gas may be made. Figure 7 for a heliox mixture shows HR 2 to have the highest efficiency for the given temperature range. It, however, offers too great a resistance to breathing. Similarly, HR 3 (an exaggerated form of HR 1) sets a lower limit for efficiency as a function of gas inlet temperature. Interpolation between upper and lower limits can determine an optimum exchanger design for the heliox gas. Figure 8 illustrates HR 2 as optimum for the case of air but again, the resistance to breathing was a problem. In the air case, however, HR 1 proved to be more efficient than HR 3, in contrast to the situation for heliox breathing gas.

Figure 9 demonstrates HR 2 to once again be highest in efficiency, but in this case the resistance to breathing 100% oxygen was less than for previous gases.

In summary, the optimization of prototypes was different for three different breathing gases. The optimum reclamator design can be closely predicted by interpolation of the limiting curves. For a given exchanger, optimum breathing gas mixtures can be recommended depending on ambient or gas inlet temperatures.

FUTURE PROPOSALS

The first proposal is to incorporate and improve the present prototype design based upon features determined during the preliminary testing period. This would include disposal discs which would increase the flexibility of the reclamator so that one design would suffice for different gases and conditions. Depth testing and interfacing of the reclamator device to the CAF regulators would be the logical second step towards commercialization. The heating up of, say, cold inlet gas to 30°C over a distance of one inch of composite packing would eliminate much of the discomfort and unnecessary energy expenditure by a diver, decreasing a potentially hazardous diver problem.

The second and third proposals deal more with the test equipment - developing a modified reclamator to seek our medical ramifications. One such example is that irregularities in the multiplex output could possibly be traced to specific bronchial defects. Another example is to determine defects in masks by using resistance to breathing tests with the heat reclamator employed as a standard.

FIGURE CAPTIONS

Figure 1: Cutaway view of the DCIEM heat reclamator, attached to a diver's breathing supply. The 'sandwich-packed' material comprising the reclamator is a composite conductor/non-conductor mesh packing.

Figure 2: Sketch showing the principle of operation of the DCIEM heat reclamator. The three rectangles represent a conductor (C)--non-conductor (N-C)--conductor (C) arrangement of only three layers of the reclamator. The conductor material has a thermal conductivity of k_1 and the non-conductor material has a thermal conductivity of k_2. The dashed vertical line on the left of the reclamator represents the diver side of the device, generally at temperature T_1, indicative of inhalation and exhalation respiratory temperature. The dashed vertical line on the right of the reclamator represents the gas supply side of the device, generally at a temperature T_2, representative of the ambient supply gas temperature. The heavy line connecting T_1 and T_2 represents the temperature drop across the reclamator with a series of h_1, h_2, h_3, h_4..... representing successive heat transfer coefficients of the successive gas layers between the constituent parts of the reclamator, an embodiment of series heat transfer. The equation in the sketch is the generalized heat transfer equation pertinent to this device where

ΔT = temperature drop across the device,

q = heat flow,

u = generalized heat transfer coefficient, and

A = cross-sectional area of heat flow.

Figure 3: Sketch of temperature response at inlet and outlet (mouthpiece) of DCIEM heat reclamator during one normal respiratory cycle.

Figure 4: Graph showing theoretical thermal efficiency of DCIEM heat reclamator versus gas inlet temperature (gas supply temperatures) for three different inhalatory temperatures (T_{in}) at mouthpiece of the device. The dots indicate experimental data with which to compare the theoretical values.

Figure 5: Graph showing the thermal efficiency performance of one type of DCIEM reclamator known as #1. Efficiency is shown plotted against gas inlet temperature; the light line indicates theoretical expectations for this prototype and the dots and heavy line indicate the experimental data and the best line of fit through it. The two vertical dashed lines demarcate the region in which theoretical values are in excess of experimental data. The specific test conditions are indicated in T_{in} = 29.5^{0}C and T_{ex} = 35.5^{o}C.

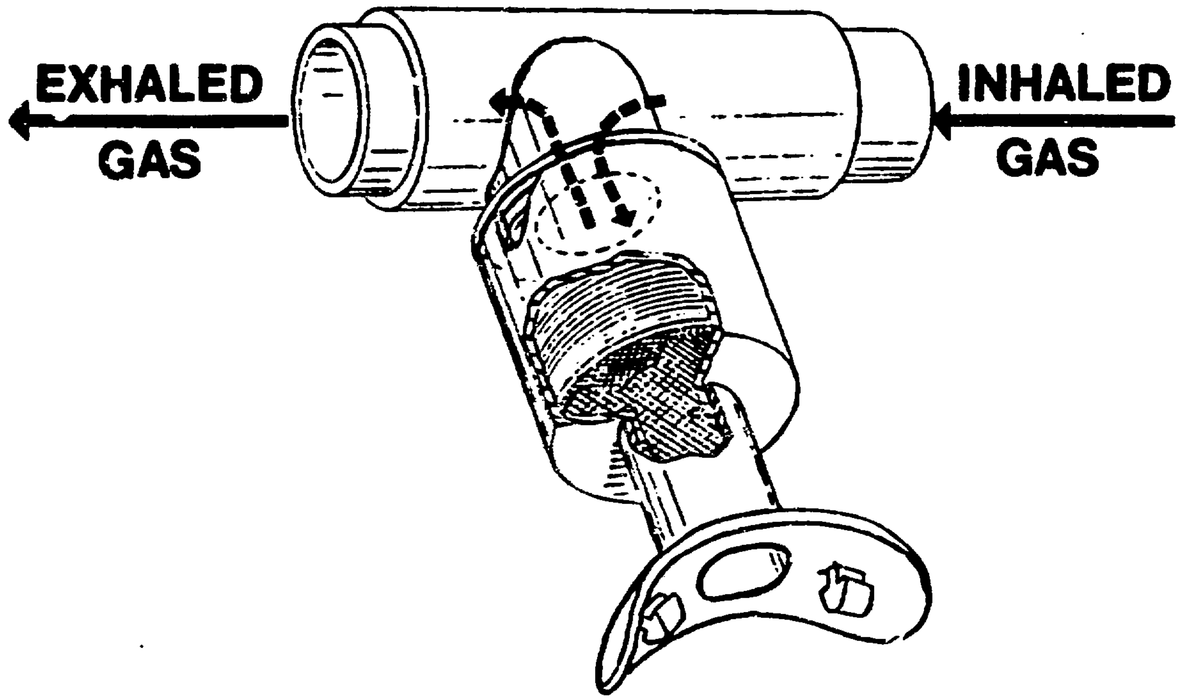
Figure 6: Graph showing the thermal efficiency of DCIEM heat reclamator #1 versus gas inlet temperatures for three different breathing gases. The dots indicate experimental data points and the heavy lines are best lines of fit.

Figure 7: Graph showing the thermal efficiency of three DCIEM heat reclamator prototypes, #1, #2 and #3, versus gas inlet temperatures (the gas being 80/20 heliox). The dots indicate experimental data points and the heavy lines indicate best lines of fit.

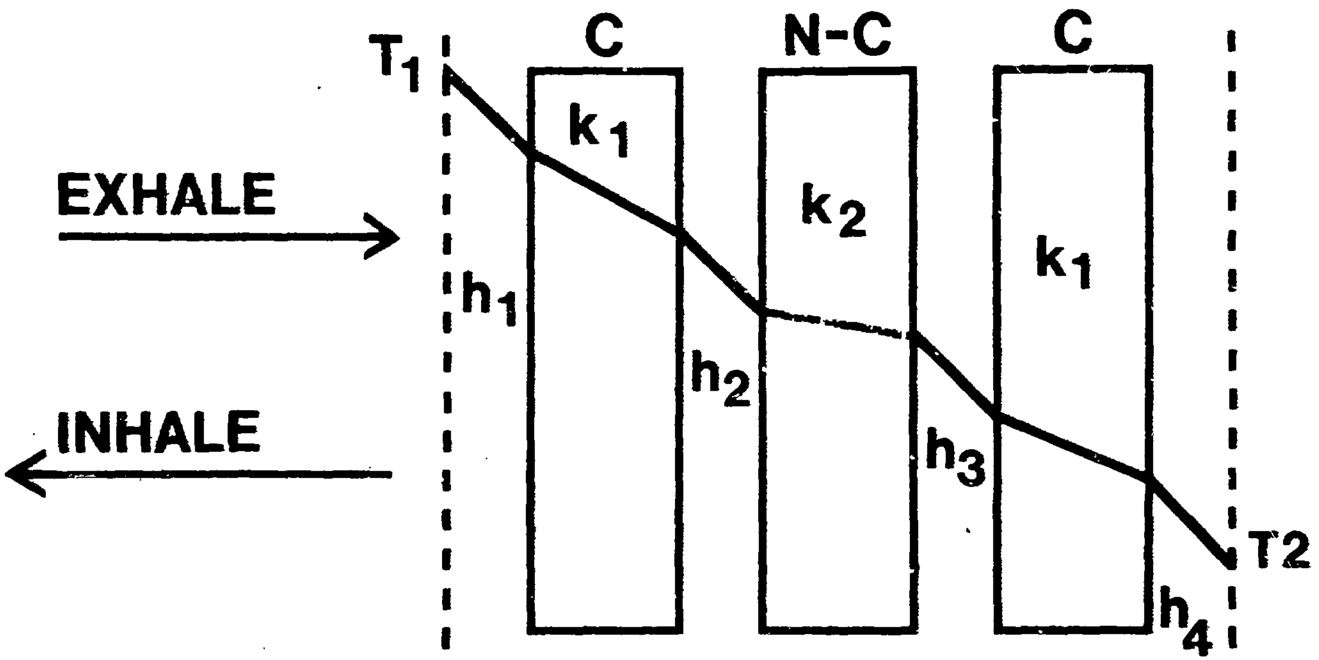
Figure 8: Graph showing the thermal efficiency of three DCIEM heat reclamator prototypes, #1, #2 and #3, versus gas inlet temperature (the gas being compressed air). The dots indicate experimental data points and the heavy lines indicate best lines of fit.

Figure 9: Graph showing the thermal efficiency of three DCIEM heat reclamator prototypes, #1, #2 and #3, versus gas inlet temperature (the gas being 100% oxygen). The dots indicate experimental data points and the heavy lines indicate best lines of fit.

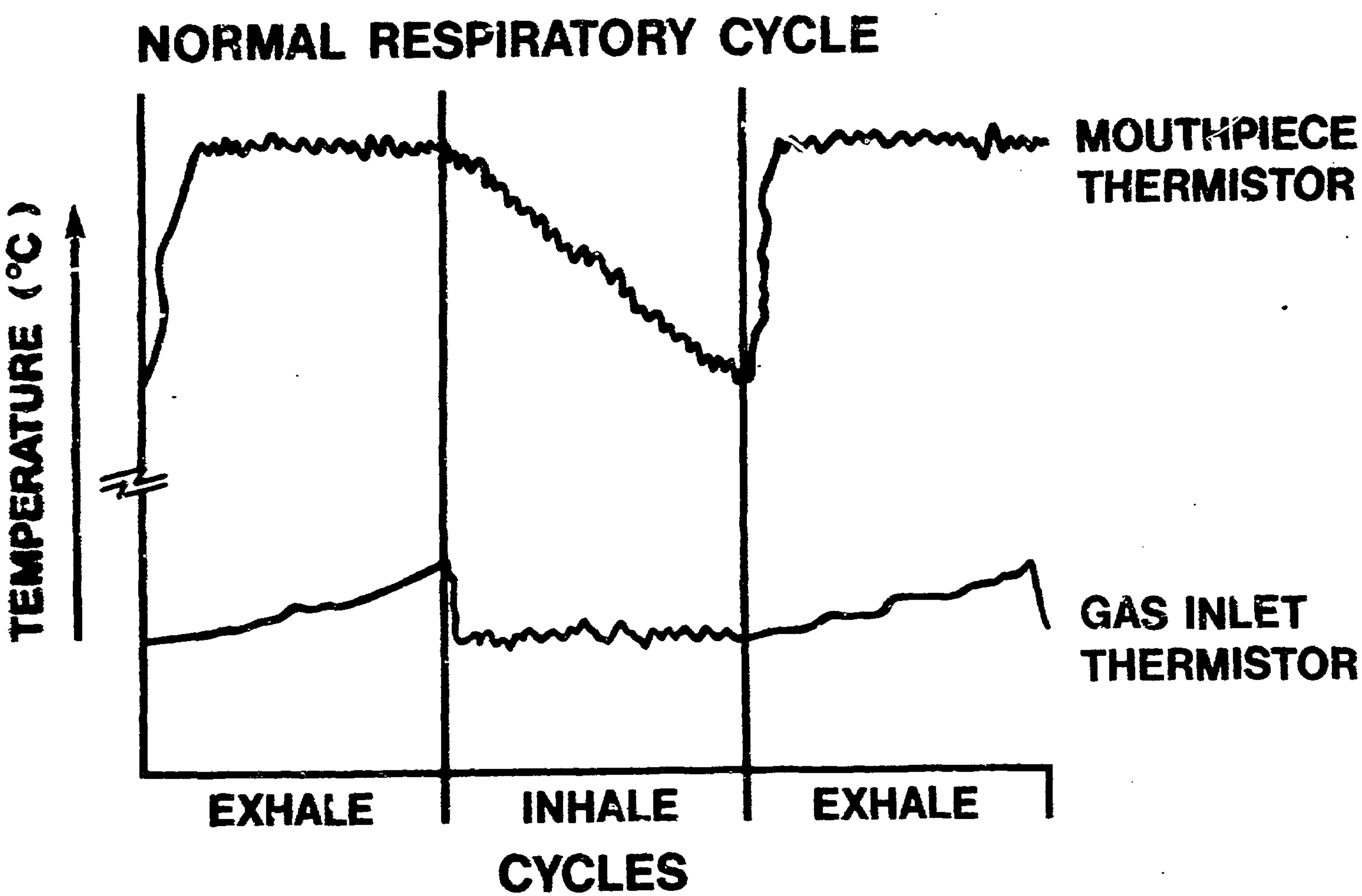
COMPOSITE CONDUCTOR / NON-CONDUCTOR MESH PACKING

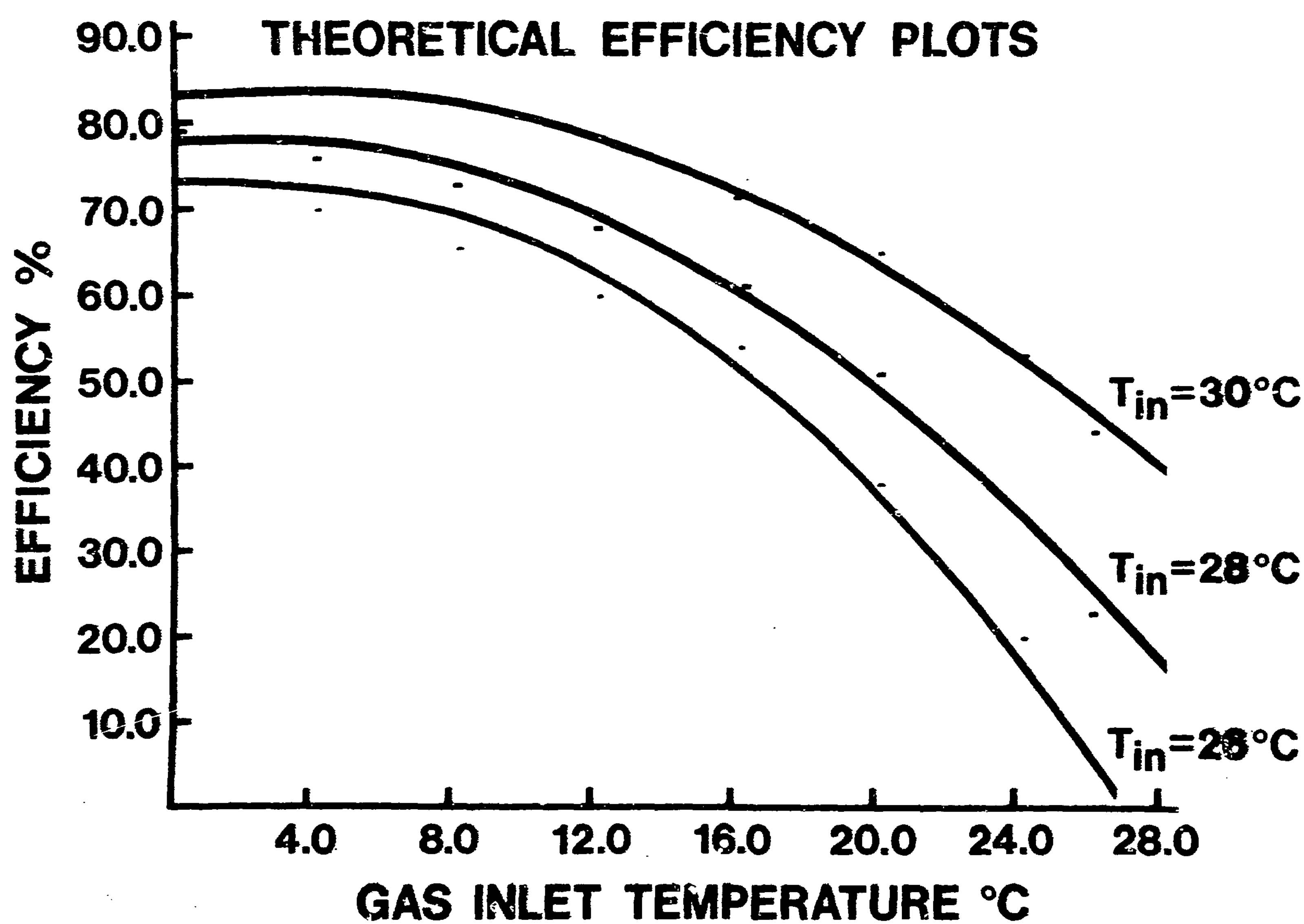


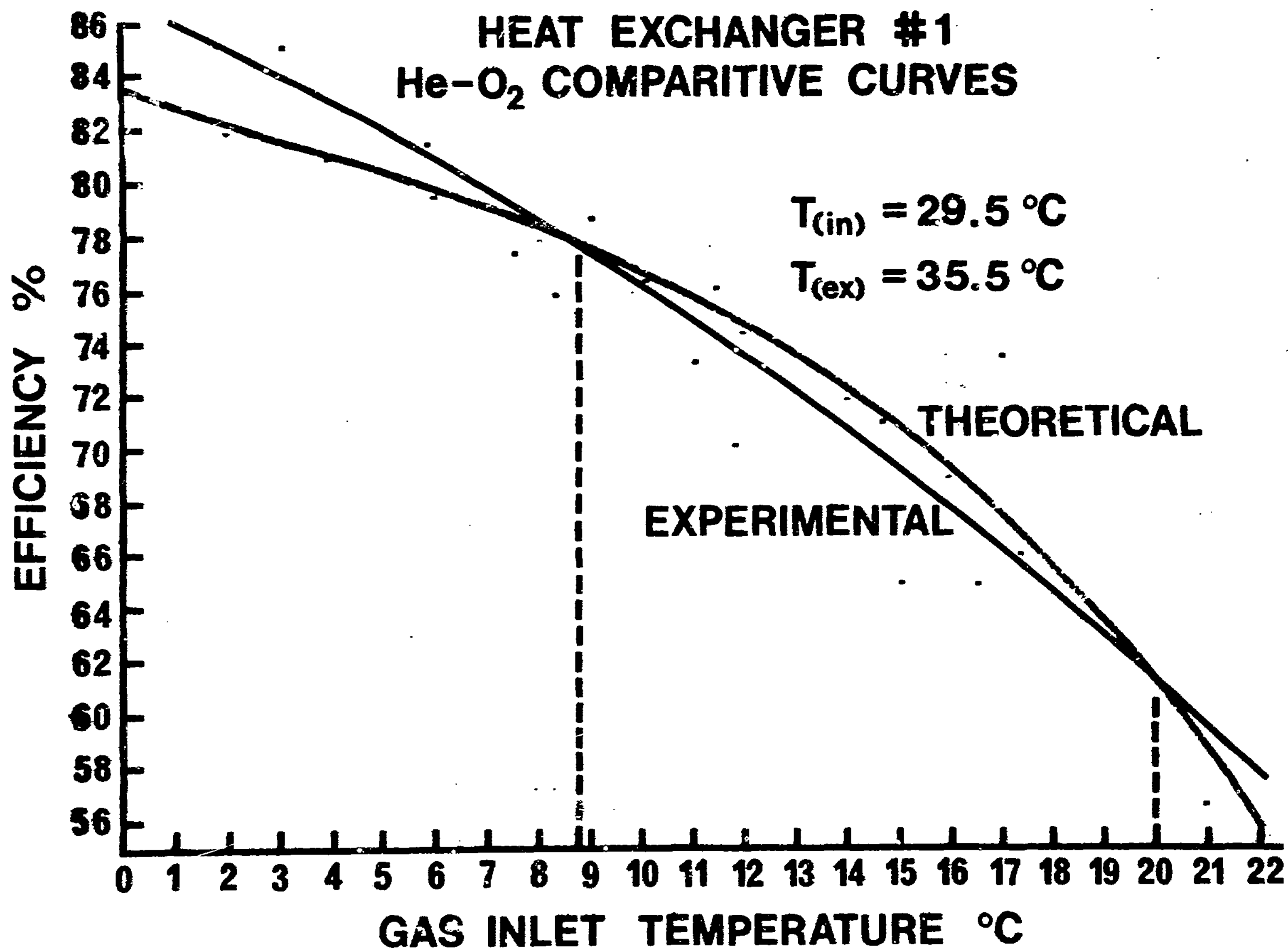
SERIES HEAT TRANSFER

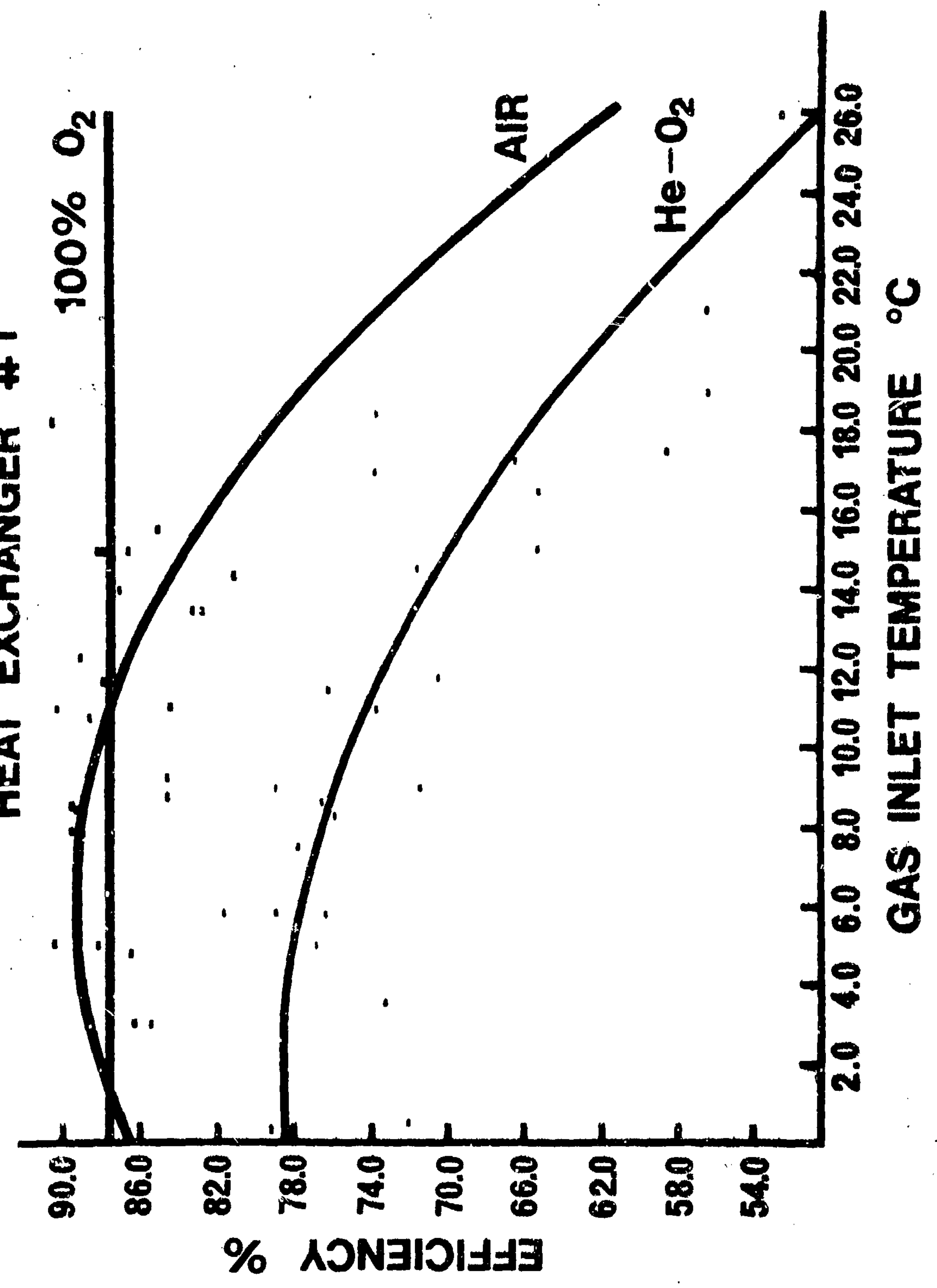


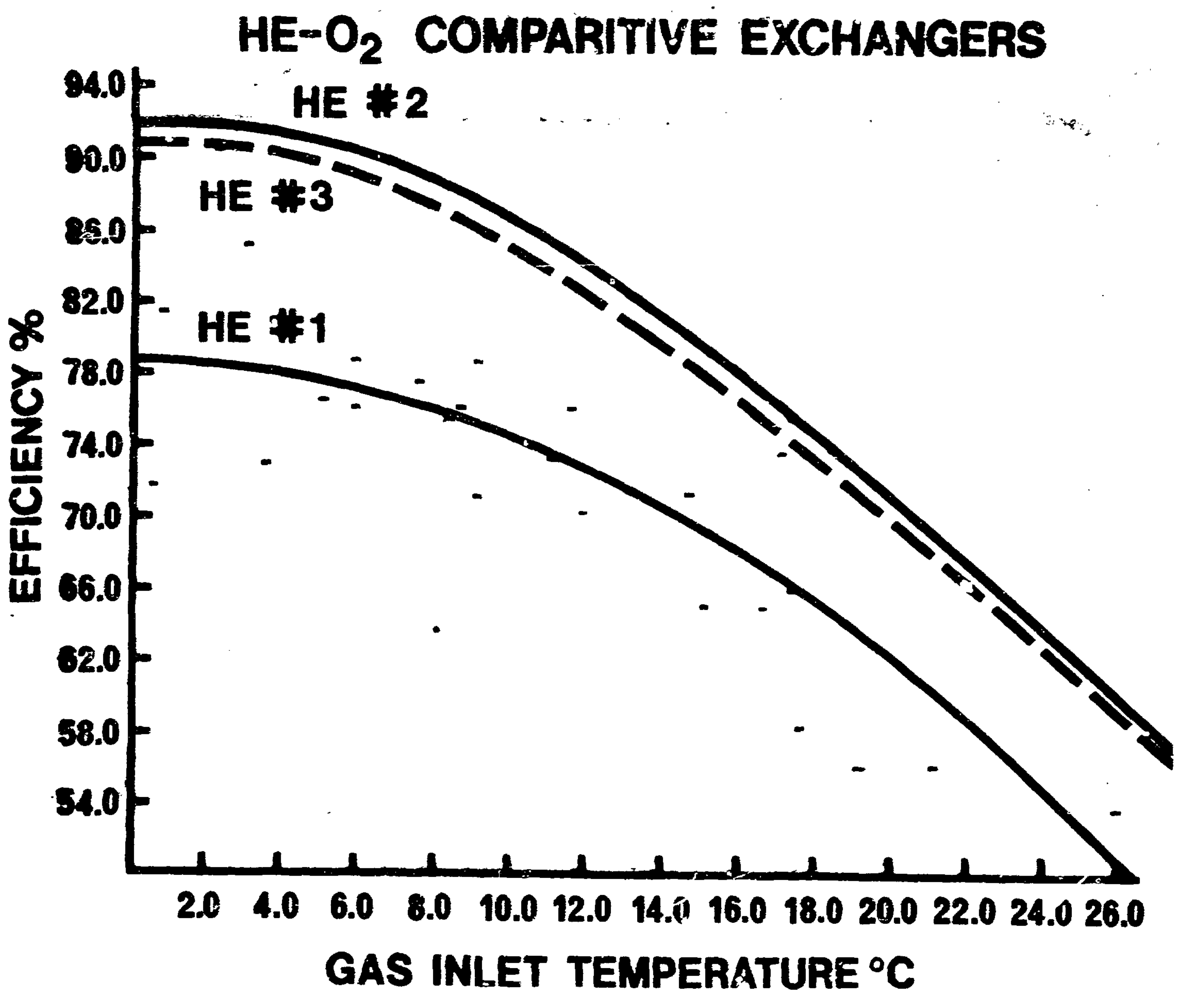
$$-(\Delta T) = q\left(\frac{1}{UA}\right)$$


NORMAL RESPIRATORY CYCLE
MOUTHPIECE THERMISTOR
GAS INLET THERMISTOR
TEMPERATURE (°C)
EXHALE
INHALE
EXHALE
CYCLES

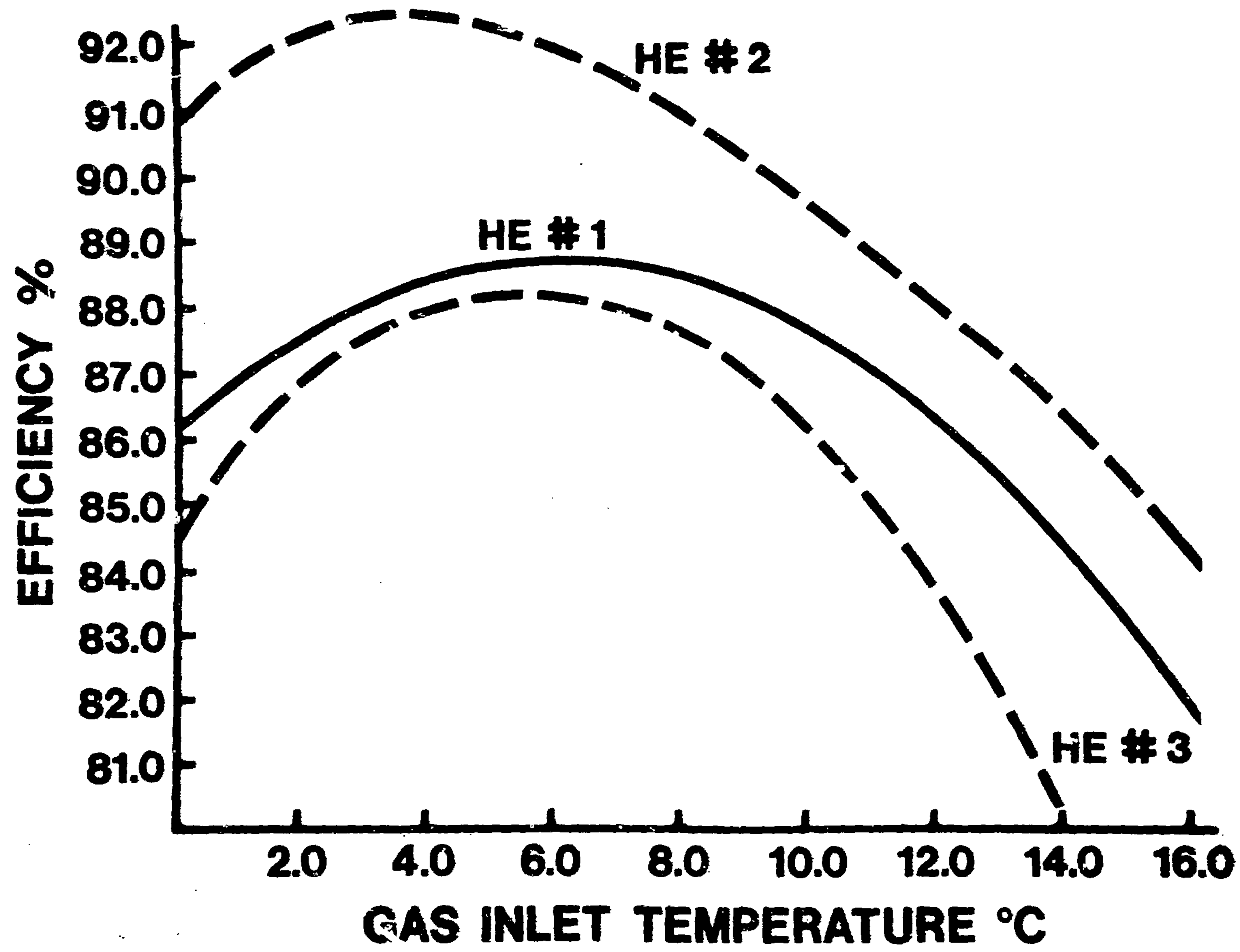

THEORETICAL EFFICIENCY PLOTS
EFFICIENCY %
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
GAS INLET TEMPERATURE °C
Tin=30°C
Tin=28°C
Tin=26°C


HEAT EXCHANGER #1
He–O_2 COMPARITIVE CURVES
$T_{(in)}$ = 29.5 °C
$T_{(ex)}$ = 35.5 °C
THEORETICAL
EXPERIMENTAL
EFFICIENCY %
86
84
82
80
78
76
74
72
70
68
66
64
62
60
58
56
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
GAS INLET TEMPERATURE °C

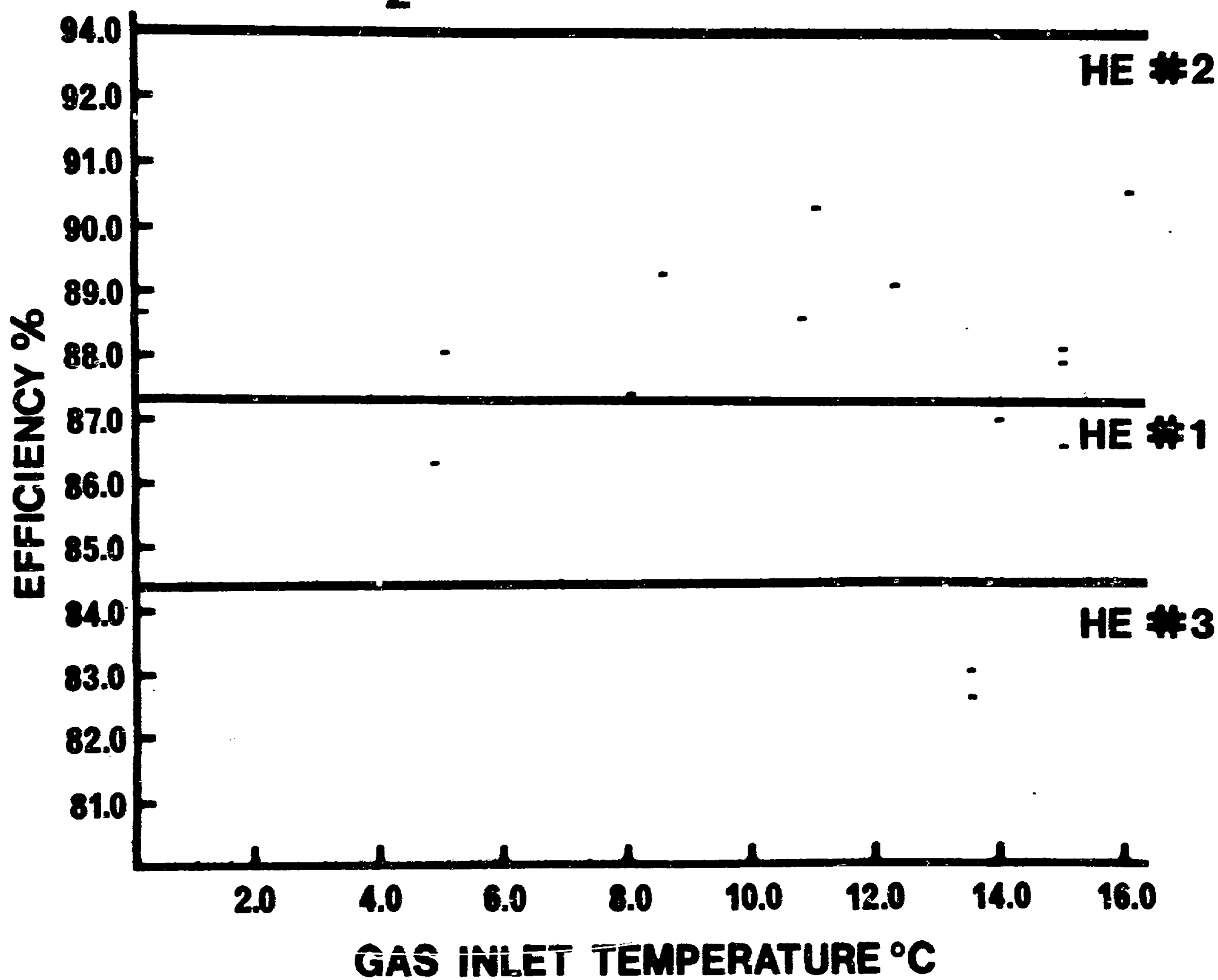

HEAT EXCHANGER #1
100% O_2
AIR
He$-O_2$
EFFICIENCY %
90.0
86.0
82.0
78.0
74.0
70.0
66.0
62.0
58.0
54.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
GAS INLET TEMPERATURE °C


HE-O_2 COMPARITIVE EXCHANGERS
HE #2
HE #3
HE #1
EFFICIENCY %
94.0
90.0
86.0
82.0
78.0
74.0
70.0
66.0
62.0
58.0
54.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
GAS INLET TEMPERATURE °C

COMPRESSED AIR-COMPARATIVE EXCHANGERS



100% O_2 COMPARITIVE EXCHANGERS



DECOMPRESSION COMPUTERS

By

Mr. R.Y. Nishi

ABSTRACT

Decompression computers have been in use at DCIEM for many years and have evolved from the first laboratory pneumatic mechanical analogue computers developed by Stubbs and Kidd in 1962 to the portable electronic digital computers of today. Pneumatic analogue computers are convenient since they are self-powered and require no external source of power. However, they tend to be bulky and mechanically complicated requiring extensive calibration and maintenance if a realistic decompression model is used. Pneumatic electronic computers are more versatile but also have the same problems as the pneumatic mechanical analogue computers. Digital decompression computers have only become possible in the last few years with the advent of microprocessor technology. The decompression model is implemented in software and the hardware can be packaged to meet operational requirements. Much more information can be presented to the diver or dive controller. Calibration and maintenance requirements are minimal compared to analogue computers. A family of digital decompression computers has been developed by DCIEM and CTF Systems, Inc. These include a line-operated desk top calculator suitable for dive planning or analysis and for real-time on-line monitoring of actual dives, a line or battery operated real-time decompression monitor and a self-contained waterproof diver portable decompression computer.

INTRODUCTION

Decompression after a dive is normally carried out by following a set of tables which are rigidly defined as to depth and bottom time. The standard procedure is to use the table for the maximum depth attained for the total bottom time. In a situation where the diver may have spent only a part of his bottom time at the maximum depth, the use of the tables results in inefficient decompression since his body has not absorbed the amount of inert gas for which the tables were designed.

A decompression computer is designed to take the diver's actual depth-time history into account in real-time, and calculate and display his optimum safe depth, ie. the depth to which he may ascend safely without running into the risk of decompression sickness. The computer is also designed to have a dynamic memory which keeps track of the diver's past dive history and which is constantly being updated with current information. This is especially valuable for repetitive

diving since the use of the tables may severely restrict the bottom time allowable or excessively prolong the decompression time for the second or subsequent dive.

DCIEM has been involved in decompression research and development since 1962 when R.A. Stubbs and D.J. Kidd designed the first pneumatic analogue decompression computer. Over 20,000 man-hours of experimental diving were conducted to develop the present series of operational decompression computers. These have been used successfully to control decompression from experimental and operational dives by both DCIEM and the Canadian Forces Fleet Diving Units.

BASIS FOR A DECOMPRESSION COMPUTER

The basis for a decompression computer is essentially the same as for the calculation of decompression tables, i.e., the same type of mathematical model of the human body is used in both cases. Mathematical decompression models generally consist of a number of discrete compartments which represent hypothetical tissues in the human body. Each compartment is characterized by some half-time or time constant which gives a measure of how fast the compartment takes up or eliminates gases as the diver's breathing gas pressure changes. These half-times may vary from 5 to 600 minutes. The pressure of the absorbed gases are calculated for each compartment and the safe ascent depth calculated by applying a suitable supersaturation ratio. The greatest value is then selected to give the diver's safe depth.

In a parallel configuration of compartments, each compartment sees the applied pressure individually (Figure 1). This is the configuration used in calculating most of the available decompression tables and is mathematically simple. In a series configuration of compartments, each compartment depends on the others. Only the first compartment sees the total applied pressure. This configuration may be more realistic in terms of the actual human body, but however, it is mathematically more complicated than the parallel arrangement. The DCIEM operational decompression computers are all based on four compartments in series.

These simplified decompression models must be implemented in hardware in order to construct a decompression computer. This can be done as either an analogue computer or as a digital computer.

ANALOGUE DECOMPRESSION COMPUTERS

In an analogue computer, the compartments are modelled on an one-to-one basis. In a pneumatic analogue computer, the compartments are represented by actual chambers which are pressurized from the breathing supply or from the hydrostatic pressure through some orifice or pneumatic resistance. The DCIEM computer was originally designed as a pneumatic mechanical analogue computer. The pressures in each compartment were measured with a Bourdon tube and the safe ascent depth calculated by means of mechanical linkages. The actual depth and

computed safe depth were presented on a dial. The Mark VS computer was a diver portable unit housed in a waterproof and pressure proof cylinder and calibrated for use to 200 feet of sea water (fsw). The Mark VIS computer was a much larger unit designed for hyperbaric chamber use or for surface supported diving. It has been used to depths of 300 fsw for experimental diving at DCIEM for both compressed air and helium oxygen breathing mixtures. It has also been used for operational dives in open water.

Because there are no size constraints, computers for surface supported diving are much easier to build and maintain than diver portable units. In order to make a diver portable unit, the computer must be small, easily read and reliable. To be marketable, the computer must be relatively inexpensive. These rather severe constraints have made commercially available decompression computers fairly simple and of limited value. The most successful commercial computer, the Scubapro Automatic Decompression Computer (SOS Decometer) is only a one compartment model. Another computer, the Farallon Decomputer, was only a two compartment model which was taken off the market because of reliability problems. The DCIEM Mark VS computer was the most sophisticated with four compartments and was marketed briefly by Spar Aerospace Products Ltd. It did not succeed commercially because of its high cost to manufacture and to maintain it.

A more versatile instrument may be designed by replacing the mechanical components of a pneumatic mechanical analogue computer with electronic components and digital displays. Pressure transducers are used to measure the pressure of each compartment. With electronics, the depth readouts can be switched easily to read in different units, for example, meters instead of fsw. The display does not physically have to be with the pneumatic section, or a remote display unit can be used. This is a useful feature where space is at a premium.

There are severe limitations to pneumatic analogue computers. Calibration of each compartment tends to be complicated and time consuming. Specially trained personnel are required for this purpose. Maintenance has to be carried out monthly, hence operating costs are high. The pneumatic section can be easily contaminated by wet or dirty gas entering the pneumatic resistances. Pneumatic computers are also generally bulky and they are difficult to change to incorporate changes in the decompression model.

One advantage of the pneumatic computers is that they are self-powered. For pneumatic mechanical units, no external source of power is required for their operation. Even for the pneumatic electronic computers, which require electrical power for the electronic components, a power failure results only in a loss of the display. The actual memory of the dive remains intact in the pneumatic compartments.

An analogue decompression computer can also be designed as an all electronic analogue computer where the compartments are simulated by resistors and capacitors and where pressure is simulated by voltage. The DCIEM electronic analogue decompression computer was designed for dive planning and analysis with output onto an X-Y plotter. Although a real-time version is also available, the computer is better suited for operation in accelerated time. It is not too suitable for diver portable use because the electronic components required for the long time constants must be extremely stable and are generally large in size and expensive. Like the pneumatic computers, drift and stability are potential problems and the computer must be calibrated frequently.

DIGITAL DECOMPRESSION COMPUTERS

Miniaturized digital decompression computers have only become possible in the last few years with the advent of microprocessor technology. With a microprocessor and a few additional components, (Figure 2), a complete digital computer can be built on one or two small printed circuit boards. The decompression computer is stored in the read only memories, the working area is in the random access memory, and the real-time clock controls the sampling rate of the diver's depth which is fed into the analogue to digital converter. The microprocessor circuitry can be packaged as a bench-top or panel-mounted instrument for hyperbaric chambers or surface supported diving, or as a diver portable unit. DCIEM and CTF Systems Inc. have developed a family of operational digital decompression computers which are being used by DCIEM and which are being adopted by the Canadian Forces. These computers are still based on the Kidd-Stubbs four compartment series arrangement which was used in the pneumatic computers. However, the compartment pressures are now calculated mathematically by software.

The XDC-1 decompression calculator is a special purpose desk top calculator for planning and analyzing dives or for real-time monitoring of actual dives. In the calculate mode, dive profiles can be generated from the numeric and special function keyboards. Parameters in the decompression model and in the dive routines which are stored in the memory can be accessed and changed from the keyboard. Two breathing gases, compressed air and a 20/80 oxy-helium mixture can be selected. In the real-time mode, on-line dive monitoring is possible by attaching an external pressure transducer unit to input the diver's depth. The calculations are updated every tenth of a minute and the computed safe depth displayed. Hence this is a dual purpose computer which can be used to replace the pneumatic analogue real-time computers or the electronic analogue dive planning computers. As the XDC-1 is line-operated only, the memory may be lost in the event of a power failure.

The XDC-2 digital decompression monitor is a panel-mounted instrument for surface supported diving or for hyperbaric chamber use. Very little training is required to use this computer since unlike the XDC-1, there are no keys to be activated. The actual depth, computed safe depth, elapsed time of the dive, and the rate of ascent or

descent is constantly displayed. A switch on the rate display changes the display to show the decompression time remaining to reach the surface. The pneumatic line from the diver or hyperbaric chamber is connected to a built-in pressure transducer. The computer can operate from 110 volts A.C., a 12-volt car battery, or from internal rechargeable batteries. The internal batteries are intended only for emergency use in case of a power failure. A set of internal switches is used to set the breathing gas mixture into the decompression program, either compressed air or 20/80 oxy-helium, to change the depth displays into meters of sea water, and to set the various output modes. An analogue output for an X-Y plotter or strip chart recorder is accessible on the front and a digital output for a remote display or for output on a teletype is accessible on the rear.

The XDC-3 portable decompression monitor is a miniaturized version which is designed to be carried by the diver. It displays the time, actual depth, computed safe depth, and the rate of descent or ascent on demand. A set of light emitting diodes will normally indicate the diver's decompression status and position relative to the calculated safe depth. The XDC-3 is still in the prototype stage and is presently housed in a pressure-proof and waterproof cylindrical case about 2.5 inches in diameter and 6 inches long. A built-in miniature pressure transducer is rated for 200 fsw maximum. The whole unit is powered by two rechargeable nickel-cadmium batteries.

There are some difficulties associated with an electronic diver portable unit. The unit may be subjected to water temperatures varying from 0 to 20 degrees C. Pressure transducers are temperature sensitive and must be compensated to read the depth correctly. Low cost miniature transducers are also not as accurate as the larger more costly units which can be used in the larger computers such as the XDC-2. Battery life is another potential problem since a power failure can result in a loss of the dive memory.

The diver portable unit is useful not only for the sport diver and the free swimming military diver, but also for individuals such as medical officers who may be going into a hyperbaric chamber periodically to treat a patient, or for an inspector on a tunnel or caisson project. In an experimental dive where several individuals may be locking in and out of the chamber, each individual could have his own personal computer to keep track of his decompression status.

All of the present DCIEM operational decompression computers can be used to a maximum of 300 fsw. For diving in excess of 300 fsw, the particular decompression model used has never been validated and does not appear to be suitable. Many more parameters besides depth and time must be considered. The XDC-4 dive management system is a microprocessor based system which is presently being developed by CTF Systems for DCIEM and which is intended for controlling dives to 600 fsw. It is a multiprocessor device, separate processors being devoted to different tasks. A decompression monitor controls the decompression, data

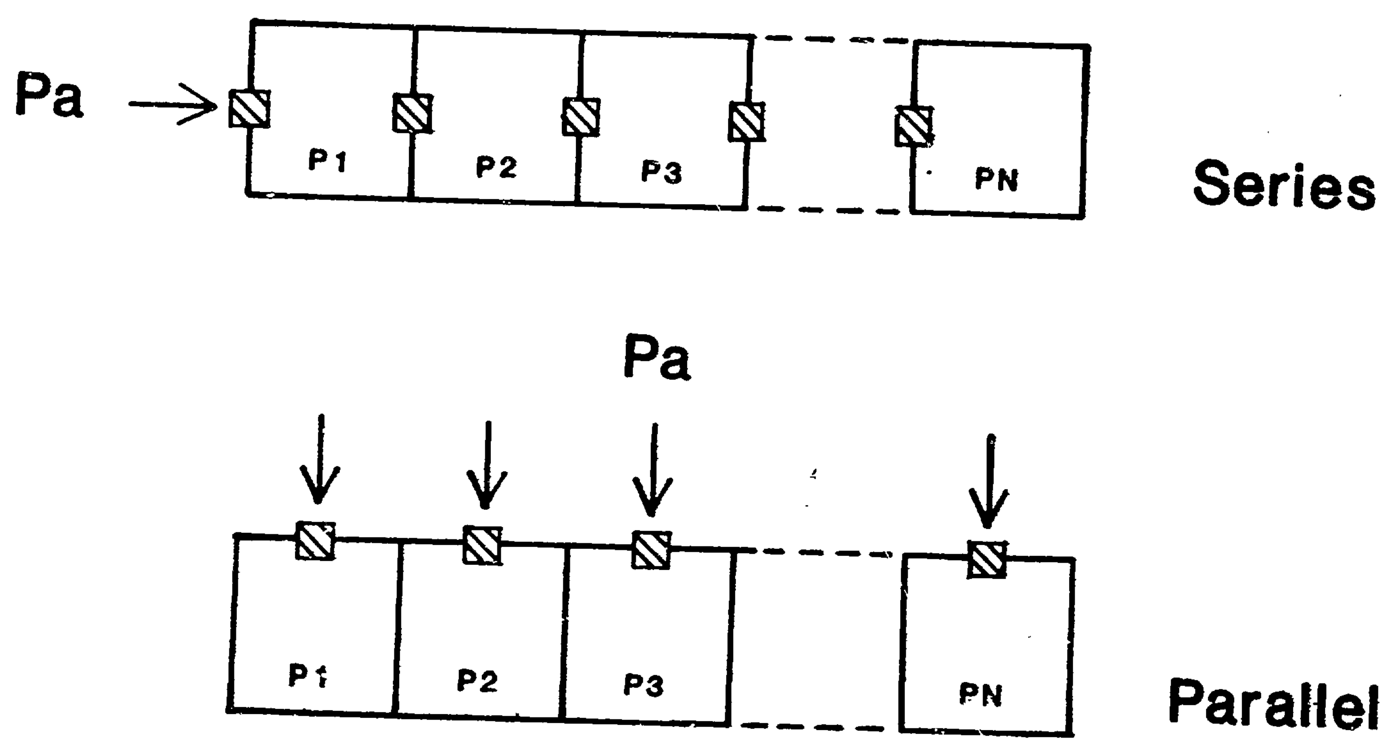
acquisition modules monitor environmental conditions and give alarms or warnings if parameters go beyond preset limits, and an auxilliary processor does look ahead calculations and indicates emergency and bailout procedures. It will not be tied down to one decompression model, hence it will be quite flexible.

SUMMARY

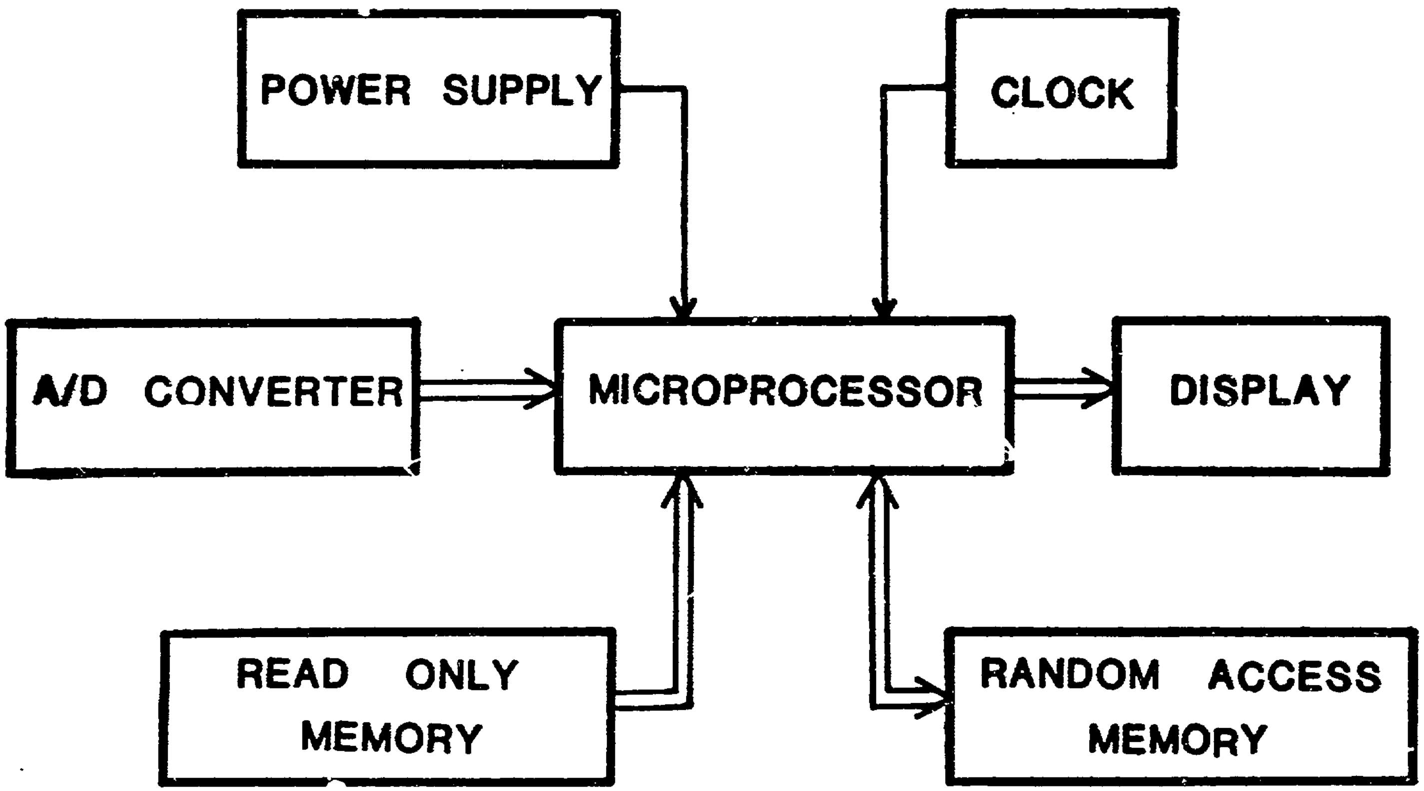
Digital decompression computers offer many advantages over pneumatic analogue decompression computers for dive monitoring. Since the decompression model is defined by the software and not the hardware as in the pneumatic computers, the computer is not restricted to one decompression model. If the model needs to be updated or changed completely, for example, on the basis of the ultrasonic bubble detection studies or the mixed gas switching theories being developed at DCIEM, then these changes can be programmed in at a later date without changing the hardware. The digital decompression computer gives flexibility in packaging and can be run off batteries where power failure is a possibility.

A diver portable unit incorporating a complex decompression model can be housed in a much smaller package than a pneumatic computer. One of the most important advantages of the digital computers is that routine maintenance and calibration requirements are almost negligible compared to the pneumatic computers. The only item that has to be checked and calibrated periodically is the pressure transducer to ensure that the depth is being read correctly. Hence, specially trained personnel are not required and operational costs will be low.

DECOMPRESSION MODEL – TWO CONFIGURATIONS



GENERALIZED MICROPROCESSOR SYSTEM



DIVER'S BREATHING AIR QUALITY ASSURANCE

By

Captain W. Burgess and Dr. H.D. Madill

INTRODUCTION

DCIEM has been active in conducting breathing gas analyses to support DND operations since about 1962. This paper will explain our work in the field, which is directed towards the production and use of high quality air, and other breathing gases in diving operations.

Our initial experience in life support breathing gas quality assurance involved the predelivery analysis of aviators liquid and gaseous oxygen to ensure conformity with Canadian Forces purity specifications. This provided a guarantee that operational flying bases were supplied only with oxygen of the highest quality. Our role in this endeavour, was to act as a central analytical laboratory, whose function was to monitor oxygen quality, and to assist in the promulgation of standards.

In the absence of either military or civilian standards controlling the quality of air and other diving gas mixtures, it was felt that a similar program would greatly benefit and enhance the safety of diving operations.

In 1971, DCIEM undertook a program to check the quality of air being used by CF Scuba Clubs, which at the time, numbered less than a dozen. Since then, this number has grown to 36. It was the intention of the program to analyze air samples from each club on a semi-annual basis i.e. immediately prior to the commencement of their summer and winter diving activities. The samples were mainly from club compressors, however, samples of commercial air used as a backup, or as a sole source of supply, were also submitted for analysis.

As will be noted in the results to follow, the value of this program for the scuba clubs demonstrated the requirement for a similar service to DND operational diving. This was instituted in early 1976. The feasibility of a central laboratory checking compressed air samples shipped in from distant areas such as Bermuda, Europe, coast to coast in Canada, has been proven.

At the beginning of the CF Scuba Club program, only two breathing air standards were available: the CSA Z.180.1, "Purity of Compressed Air for Breathing Purposes" and a CF Engineering Order. However, neither of these provided a suitable guideline for the assess-

ment of divers air purity. Since that time, the CSA Standard has been twice updated and a CF Standard stating purity requirements for divers air, and other gases has been promulgated.

METHODS

a. The program utilizes high pressure steel cylinders that are used to transport both high and low pressure gas samples to the central analytical laboratory. The bottles are equipped with divers K-valves which facilitate the collection of samples. After each analysis, the cylinder is washed thoroughly with organic solvent (trichlorotrifluoroethane), purged with pre-purified dry nitrogen gas, and evacuated prior to subsequent use. The charging line is fitted with a side valve to allow line purging to eliminate residual moisture and other contaminants. The cylinders are DOT approved for shipment of air samples by air and rail.

b. The sample cylinder is firmly secured in a 3/4" plywood shipping case to prevent any movement during transport. The valve is easily accessible when the case lid is opened and the sample may be collected without removal of the cylinder.

c. When a sample is received at the laboratory, the gas is transferred to an infrared sprectrophotometer variable path gas cell, which may be pressurized to 140 psia. An infrared spectral analysis is then carried out to look for the presence of trace contaminants such as carbon monoxide, carbon dioxide, methane, ethane, acetylene, ethylene, halogenated hydrocarbons and many others, in part per million concentrations.

d. An oxygen analyzer is used to determine the oxygen concentration in pure oxygen, air and other mixed gases. A thermal conductivity gas chromatograph is also utilized to determine oxygen and nitrogen content in air samples. Low oxygen content may reveal improper mixing, or sometimes oxygen depletion resulting from corrosion activity.

e. A Show Hygrometer and/or an Alnor Dewpointer are used to determine moisture content in all gas samples.

f. An MSA Total Hydrocarbon Analyzer is used as a first line screen for the presence of condensed hydrocarbons in compressed breathing air samples.

g. The two main standards used in our quality assurance program are:

(1) D87-003-000/SG-001 5 Jan 77--This is a Canadian Forces Standard which outlines the purity requirements for breathing air and oxygen, helium and nitrogen gases, used to prepare divers breathing gas mixtures.

(2) The Canadian Standard CSA Z180.1-1973, "Purity of Compressed Air for Breathing Purposes". A 1977 update to this standard has been accepted by the CSA technical committee, and has been submitted to the steering committee for final approval. The new edition will provide greater flexibility for water vapour limits in compressed breathing air and will introduce new clauses dealing with indoor and outdoor breathing air systems.

It is our opinion that oil content should be limited to $1 mg/m^3$ because oil is a complex mixture of hydrocarbons, and is known to contain aromatics, which themselves are toxic. We also feel that carinogenics may be present also.

At rest man breathes 10LPM air. Working divers may breathe 30LPM or ($1.8 m^3/hr$). A Standard allowing $5 mg/m^3$ oil would therefore dose a working diver with 9mg oil/hr. Said in another way, a 70 ft^3 scuba tank would yield 10mg/oil, if contaminated at the $5 mg/m^3$ limit.

Excessive moisture content in compressed breathing air may cause

a. corrosion of steel air tanks; and

b. regulator freeze-up.

The Standard allows 27 ppm water vapour or -65°F dewpoint at (NTP). This corresponds to a pressure dewpoint of +40°F in a tank pressurized to 3000 psi. If water temperature is at, or below 40°F, the water vapour will condense out. Further cooling will result from expansion of the gas from 3000 psi to 140 psi in first stage of regulator (10°F). If water is near the freezing temperature, regulator freeze up may occur. The dewpoint allowed in the standard is therefore borderline.

Results

A review of the Canadian Forces Scuba Clubs performance in meeting the breathing air purity requirements, has shown that in 1974 approximately eighty-five per cent of the clubs failed to meet the water vapour standard of $0.02 mg/m^3$ (-65°F). In addition, about twenty-seven per cent of the clubs failed to meet the 5 ppm limit for carbon monoxide. However, in the ensuing years 1975 and 1976, their

performance improved considerably, so that during 1976 only twenty-eight per cent of the clubs failed to meet the standard for water vapour, and only twelve per cent were failed as a result of carbon monoxide content. This improvement in the clubs' ability to meet the purity requirements for water vapour and carbon monoxide is attributed to a continuing education and feedback to the clubs, and a strict control over the sample cylinders used in the program.

During this same three year period, air sample failures due to other contaminants showed an increase from eight per cent to fifty-three per cent. This apparent reversal in trend was actually due to the introduction of new and improved analytical procedures and the development of a new method which allowed quantitative analysis of condensed hydrocarbons in compressed breathing air samples.

To give you an example of the Quality Assurance Program as it applies to operational diving, I would like to trace the history of two separate systems; one, an LP system (studied over a one year period) and a short study of an HP system.

LP System

Two air samples received over a two week period indicated the system to be grossly contaminated with oil levels of 110 and 150mg/m^3. Following corrective maintenance, the oil contamination was reduced to 20mg/m^3. One week later 60mg/m^3 of oil was recovered from an air sample, indicating complete recontamination of the subject system.

Following cleaning and head gasket replacement, the system contamination was eliminated, as shown by analysis of air samples. However, this was to be a short relief because the next air samples received, one and two weeks later, again indicated oil contamination buildup to 10 and 30mg/m^3 respectively.

This cycle repeated over the next three months causing the users to install ancillary filter cartridges. However, subsequent air samples again showed gross oil contamination with levels of 160-170 mg/m^3 being detected. This may have been due to incomplete removal of condensed oil from the entire system, prior to installation of the ancillary filter cartridges. We were also of the opinion that the filters installed may have been incapable of removing oil from a system where high moisture levels are present. Following a thorough clean up of the total system, 5 of 6 samples received were found to have 1.0mg/m^3 oil present.

HP Syst .

The HP system was studied over a 20 hour compressor running time to establish the required frequency for filter changing. Starting with a zero oil level, 4 air samples were collected at 5, 10, 15 and 20 hours compressor running time and each was analyzed to determine the oil content.

The results were as follows:

Sample 1 at 5 hrs	1mg/m^3
2 at 10 hrs	1.5mg/m^3
3 at 15 hrs	1.5mg/m^3
4 at 20 hrs	3.0mg/m^3

The study indicated that oil exceeds what we consider should be the maximum allowable level of 1mg/m^3, sometime between the 5th and 10th hour of compressor running time.

CONCLUSIONS

1. The program has provided ample proof of the value of quality assurance, and of having a central analytical laboratory.

2. It has also emphasized the need for "good standards" which provide sound guidelines, and encourage a responsible attitude toward the production and use of pure breathing air.

3. Analytical results have provided valuable information about types of purification, the correct sequence for purification media, and its life expectancy. In addition, the types of contaminants found in divers air have demonstrated the need for rigid maintenance schedules.

4. The feedback and education towards the production of high quality divers air, through our quality assurance programs has been amply demonstrated.

This Institute supports the belief that there is no such a thing as a "breathing air compressor"; rather, pure breathing air is produced through the correct combination of compressor, purification system, piping system, receivers and a thorough knowledge of operation and dedicated maintenance procedures. These factors in combination, form a compressed "breathing air system", capable of producing high quality breathing air. This applies equally to high and low pressure systems.

THE ROLE OF DIVING

IN THE

CANADIAN OFFSHORE MINERAL SEARCH

By

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Department of Energy, Mines and Resources

The assistance of Steve MacInnis, Madeline Robert and other officers in the Resource Management and Conservation in the preparation of this paper is gratefully acknowledged.

Mr. Chairman, gentlemen and colleagues, I should like to talk to you this morning about the past and future role that diving plays in mineral development. Canada has the longest coastline of any country in the world, and one of the largest continental shelves. This shelf area has not been extensively explored or developed and reasons that come to mind apart from the obvious difficulties posed by the water are the extreme climatic conditions in much of the shelf area and the mineral wealth onshore that has inhibited the need for minerals from offshore. In terms of economic value of production in coastal regions at the present time, the extraction of sand and gravel for general construction purposes is the most important mineral activity. It is anticipated that this will be the case for at least another decade.

There are several other minerals found along the coast with some prospect of development. Minor amounts of gold have been gleaned from beaches off Nova Scotia and British Columbia. Occurrences of heavy minerals such as magnetite, illemenite, hematite, luxoceme, rutile, garnet, anatane and zircon have been reported in the Gulf of the St. Lawrence, and in many places along the coast of Nova Scotia. However, none of the deposits are extensive and to date there is no commercial development of these finds. In northern Cape Breton Island near Sydney, coal mines extend several miles under the sea through shafts originating on land. At this moment, the Glomar Conception drillship is engaged in a core-hole drilling program to gauge the extent of these offshore coal reserves. Because of mechanical limitations to the ventilation systems, the shafts cannot be extended much beyond their present 3½ miles without a vent to the surface. For this purpose some sort of artificial island or platform will have to be constructed. I mention this and the other mineral finds to indicate the possible areas in which divers may be involved in offshore mineral development in the future.

In common with many other marine areas of the world, Canada's best potential for significant economic development in the offshore lies in the discovery of oil and gas. In terms of dollar expenditure, the exploration effort in the Beaufort Sea, the Labrador Sea, the Scotian Shelf including the Sable Island area, West Coast, Hudson Bay and offshore the Arctic Islands must be regarded as a major marine industry. To give you some idea of the expenditures involved, an average offshore drilling rig on the East Coast with support services and consumable material included, costs $50,000 to $100,000 per day. A single well may cost over $5 million and exploration costs to date off Labrador, Newfoundland, Nova Scotia and the Gulf of St. Lawrence total about $400 million. In the Beaufort Sea, a single well may go as high as $30 million dollars. As well as being major employers of professional divers, it is the search for oil which has pushed the diver into ever deeper waters. The frigid waters encountered in Canada's offshore frontiers has not yet stymied the advance of this technology.

To date, every drilling vessel engaged in the offshore oil search has either had divers continuously on board or, in a few cases where the shorebase has been close, available on a 24-hour basis. Assignments range from recovering lost equipment from the seafloor to setting corrosion caps on suspended wells, to observation of suspected defects of the drilling system to placement of sandbags and other anti-erosion devices around the legs of bottom-sitting platforms. There have been many occasions when the ingenuity of the diving industry and the physical capability of diving people were challenged to enable operations to be completed at a suspended well and thereby ensure that no possible threat of pollution from a well located in deep water could exist. In each of the following cases, the original drilling vessel was forced off the location by a storm or iceberg. In each case, the task of the divers was to observe the damage first hand, attach hydraulic control lines to function mechanisms on the old blowout preventors and ensure that the attachment and operation of new risers and preventors proceeded satisfactorily.

On October 18, 1969, the drillship, Wodeco II was literally blown off theAquitaine et al Hudson Walrus A-71 well by winds of 100 mph. The well is located in Hudson Bay, 210 km from land in 179 metres (587 ft.) of water. The well was thought to be adequately sealed as the blowout preventors had been closed prior to being swept off location. However, the marine riser fell to the floor of the Bay and the well was not considered to have been properly plunged and abandoned. In September, 1974, Aquitaine Company of Canada returned to the well with the specially built semi-submersible Pentagone P-82.

On board were a Comex diving crew of 18 people including a manager, assistant manager, diving doctor, electrician, mechanic, chief caisson master, cassion master, five alternate divers doubling as surface tenders and two diving crews of three men each. These six divers were under saturation for nine days and three hours followed by 3½ days of decompression.

The crew descended to the wellhead in a bell and one remained inside at all times while the two others did the physical work outside the bell. A total of 11 wet dives were made for a total of 32.04 hours outside the bell. Maximum working time for any one dive was four hours. Thanks to their efforts, the well was properly abandoned. In addition, the marine riser and other large pieces of equipment were recovered from the floor of the Bay.

On October 8, 1971, the Drillship Typhoon was forced to leave the Tennco et al Lief E-38 location because of an encroaching iceberg. The iceberg reversed course after having once gone safely past the ship and posed an unexpected threat from the rear so the departure was necessarily hasty. This well is 170 km from the Labrador Coast in 168 metres (550 ft.) of water. In late July, 1973, the drillship Pelican under contract to Total Eastern Exploration returned to the location. It brought essentially the same Comex crew that was to work on the Walrus well the following summer. The necessary hydraulic lines were attached and the BOP stack was recovered in three working dives. The drillship was on location a total of six days including the time required to run the cement abandonment plugs.

On October 3, 1974, the drillship Havdrill (now the Canmar Explorer III), suffered a failure of the marine riser and control lines just above the stack while on the BP Columbia Bonavista C-99 well. This location is 140 km from the nearest piece of Newfoundland real estate and in an unprecedented 329 metres (1080 ft.) of water.

In June of 1975, BP Development returned to the site with the same vessel and a Comex crew to establish a world depth record for a working dive. Again it was necessary to attach control lines to the BOP and riser connector functions. The task was accomplished from a diving bell stationed at 316 metres (1040 ft.) as the working area was 13 metres above the seafloor. The task was accomplished with three divers by the bell for a total of 10 hours. Divers left the bell on the last two dives and were outside for a total of four hours. The broken stub of the riser was recovered and the well was deepened beyond its suspended depth of 12,090 feet.

In all of these cases, the ambient temperature was below the freezing point of fresh water and hot water suits heated with water at 105°F were used to enable the divers to survive. Comex have prepared a film called "Plongeurs Du Froid" which covers these exploits more vividly than my mere words. An English version is on file at EMR and anyone wishing to arrange for its loan can contact me later.

In the fall of 1972 near Sable Island, the Mobil Tetco Thebaud P-84 well was drilled using the semi-submersible Sedco H in the on-bottom configuration. Due to the strong currents which caused sand erosion in the vicinity of the rig, protective matting and sandbags were placed around each of the three cassions supporting the structure. Only scuba gear is required in the 27 metre waters but the strong currents make diving hazardous. At the present time, Dominion Diving is performing a similar task around the four legs of the jack-up platform

Gulftide, now drilling in the vicinity of the Island. In the early stages, 15 divers were on board and a crew averaging six divers remains on board as drilling continues. Work is only possible one hour on each side of slack tide and during daylight hours. Plastic bags, chain link fencing and cement grout have all been used to hold the sand in place and thereby maintain stability around the legs.

In Arctic waters, Pan-Arctic Oil has developed techniques for drilling from thickened ice platforms. This work is not diver assisted but schemes for the completion of underwater well-heads and laying of flowlines from production wells are being field-tested this winter in a 58 metres (190 ft.) of water. Divers will be on standby during this operation and installation of a full-fledged production system will undoubtedly require considerable diver assistance. In April, 1976, the JIM atmospheric diving suit was used to inspect the BOP stack and perform a series of assigned phone tasks at the Pan-Arctic Tenn CS N.W. Hecla M-25 well drilled in 275 metres (900 ft.) of water.

In the Beaufort Sea, divers operate routinely from the three Can-Mar drillships and frequently from the large dredge barge. Temperatures here range from four degrees Celsius at surface to minus two degrees at the sea floor.

It should now be apparent that the production of vital hydrocarbons from subsea completions in Canada's frigid waters is equally challenging to those who work in Rathats as it is to wearing hard hats.

SUBMERSIBLES AND DIVING IN DFE

By

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Department of Fisheries and Marine Services

ABSTRACT

To obtain a true understanding of our marine environment, and to gain adequate knowledge of our marine resources, the Department of Fisheries and the Environment continually seeks better and safer methods to explore, conduct research, acquire data and conduct analysis of the underwater world. Submersibles (manned and unmanned) and divers are employed to achieve these objectives.

PISCES IV

In 1971, as a result of some "moral suasion" from the United States Government, the Canadian Government cancelled the export permit for the sale of PISCES IV to the Soviet Academy of Sciences. The U.S. objection to the sale was on the use of strategic materials (HY100 steel) and the transfer of technology.

This put International Hydrodynamics in a precarious financial position—a situation created by Government decision—or bowing to overt pressure. HYCO's predicament was recognized and it was decided that PISCES IV would be purchased by the Government and assigned to one of the vessel operating departments. DND had the operational expertise—but no programs to support. DOT had neither. DFE and EMR had research programs requiring a submersible—but no operational expertise. A review of the correspondence and minutes of meetings on this subject indicated a great deal of manoeuvering on the part of the involved Departments—in fact reminded me of Brer Rabbit and the raspberry patch. Departments would not admit they wanted the submersible. Eventually Cabinet decided the submersible would be operated by DFE with other departments (DND in particular) assisting as required in support of DFE's submersible program. The decision that a civilian department should own and operate PISCES IV was predicated on the assumption that it would provide a more flexible response to providing contract/charter service to the Soviet Union if requested. This situation never materialized. After an interesting building, trial and error training period DFE accepted the PISCES IV on the 5th of October, 1977.

Initially the crew were all Canadian Forces (Sea Element) "NAVY" personnel (submariners and divers). After a three year transition period the crew were civilianized (Public Servants - Ship's Officer Classification). Some of the service personnel are still with the program.

The submersible has provided DFE and other Departments with a viable manned submersible program. PISCES IV has made a total of 633 dives--540 since acceptance by DFE and has a full program planned. However, the operations have not been problem free.

The HYMAC motors had brush problems. DFE required 100 hrs M.T.B.F. HYCO eventually achieved this objective. DND subsequently required 200 hrs M.T.B.F. which I understand has been achieved.

The Ballast Pump was not very efficient. It failed at about 600 feet during builder's trials, was modified and failed again during trials at about 1600 feet on the first dive to 2400 feet. This required another modification. This was a single acting pump which really never was satisfactory. A double acting pump was developed and fitted in February, 1975 and performed reasonably well until about a year ago. It was clear that if PISCES IV was ever to dive in deeper water (more than 2000 feet) the entire ballast system would have to be replaced with a proven system. A new system was installed this spring, a system which HYCO has installed in several of their 6600 ft (2000 metre) submersibles.

The Syntactic Foam has, since acceptance progressively deteriorated. The rate and amount of water absorption was increasing with consequent degradation in buoyancy. Therefore, until the foam is replaced PISCES IV has been restricted to 500 feet.

Surface Support Ship

The Cabinet decision assigning PISCES IV to DFE included a surface support ship. DFE requested approval to build a support ship. When this request was reviewed by the Ministers it was decided that DFE should charter a submersible support ship from the private sector. In July, 1972 22 firms were invited to tender on a surface support ship--14 firms acknowledged the tender call--8 firms submitted tenders, five of which merited consideration. After a rigorous evaluation a short list of three firms was developed (one firm on this list withdrew its offer). The contract was subsequently awarded to Christensen Canadian Enterprises Limited of Halifax, the lowest qualified bidder.

In the interim before the chartered vessel was ready the Department chartered the support barge "Gulf of Georgea 192" from HYCO. This proved to be a wise decision, but not without its problems--because by the time the chartered vessel was on charter the submersible crew was thoroughly trained and most of the bugs had been eliminated from the submersible.

The M.V. "PANDORA II" was accepted on charter on 12 March, 1974 and was soon at sea on trials. The marriage of the two systems was now consumated and throughout April both were conducting trials and training. The system has been extremely successful.

PISCES IV - DIVES

(MARCH 72 TO 30 SEPT 77)

BUILDERS TRIALS	63
CREW TRAINING	113
CHECK OUT	19
EQUIPMENT TRIALS	82
NAVIGATION SYSTEM TRIALS	2
BOTTOM POLLUTION SURVEY	65
DUMP SITE SURVEY (7 MINE TAILINGS)	23
HELICOPTER RECOVERY	8
ARCTIC ACOUSTICS	5
SUPPORT SHIP TRIALS	48
GEOLOGICAL SURVEY (10 ARCTIC)	41
USER FAMILIARIZATION	4
OCEAN TURBULENCE STUDIES	62
TORPEDO RANGE CABLE INSPECTION	6
FROZEN SEA RESEARCH (OIL WELL BLOW OUT)	2
CHLORINE TANK CAR SEARCH	11
CBC (TV & RADIO)	3
INSTRUMENT RECOVERY (PANDORA'S ANCHOR)	14
PRAWN STUDY	4
BIOLOGICAL SAMPLING	21
SPONGE STUDY	22
VOODOO SEARCH	15
TOTAL	633

Unmanned Systems

In response to an unsolicited proposal from McElhanney Offshore Sweeping and Engineering Limited of Port Moody, the Department (CCIW Inland Waters Directorate of E.M.S.)with bridge funding from D.S.S. Science Procurement Branch acquired the T.R.O.V. 1B (Tetherall Remotely Operated Vehicle) with a maximum operating depth of 1200 ft.

This submersible is used to support underwater programs in the Great Lakes. To illustrate the effectiveness of this system, one of the first programmes investigated two Hom contacts in 270 feet of water off Port Dalhousie. These contacts had previously been acquired by Magnetometer and Side Scan Sonar. The T.R.O.V. then classified these contacts as two ships believed to be the "HAMILTON" and the "SCOURGE" which sank during a storm on August 8, 1813. One is upright, is remarkably well preserved with many artifacts in the vicinity.

In March and April of this year a joint program by: E.M.R. - Geological Survey of Canada, E.M.R. - Polar Continental Shelf Project, D.F.E. - C.C.I.W., Panarctic Oils Limited, I.S.E. (International Sumbarine Engineering Ltd.) (formerly McElhanney) -- to determine and assess T.R.O.V.'s performance in the Arctic environment was conducted off Drake Point, Melville Island. This program involved the submersible's ability to:

a. cope with the harsh environment during all phases of the operation;

b. operate through a 2 to 5 metre square hole from the sea ice platform; and

c. study the underside of the ice and the seabed using the following techniques:

   (1) video-taped television,

   (2) colour photography,

   (3) sample recovery,

   (4) side scanning.

The T.R.O.V. was suitably modified for this program with larger port and starboard thrusters and a surface power source.

On arrival on the ice site a hut was set up and a hole cut in the 8-foot thick ice. It was estimated that approximately 13 tons of ice were cut and moved out of the hole.

The T.R.O.V. made dives of approximately 45 minutes each. Despite some equipment problems (still camera) and component failures (mainly solenoids) the program was considered a success. However, to ensure maximum results before going north again, it is intended to do more work through the ice in the Great Lakes.

This system has much to offer. We are now able to thoroughly investigate and survey a work-site without putting a diver in the water, or for that matter, a manned submersible. Thereby enhancing safety and maximizing economy of operation.

The Bedford Institute of Oceanography at Dartmouth has developed the "Sea Rover", a cable controlled bottom crawler which has been reasonably successful. The main problem is not knowing precisely where the vehicle is relative to the controlling platform. It is anticipated that a bottom referenced relative position navigation system will enhance the system's effectiveness. Also the Fisheries Biological Research Station at St. Andrews has developed a series of towed underwater vehicles.

T.U.R.P. (Towed Underwater Research Platform) was a towed sled. Two divers held on and were towed over the survey area. This gave a rapid visual observation of sea weed beds, oyster beds, scallops, lobsters, etc. in shallow water. The divers could record their observations by movie and still cameras. However the divers endurance was severely limited--not much more than 30 to 45 minutes even in summer months.

B.R.U.T.I.V. (Bottom Referenced Underwater Towed Instrument Vehicle) was developed to carry a series of instruments and to eliminate the divers. By using an ingenious system of an Echo Sounder and a self powered hydraulic control system MK I is able to maintain a preset height off the bottom (± 6 inches) with a maximum operating depth of about 400 feet.) This system has cameras and other instruments and has been quite successful.

B.R.U.T.I.V. MK II is now under development and will be a more rugged vehicle with improved electronics and controls with a larger payload. Anticipated maximum operating depth--600 feet. MK II will also have more applications--T.V./Movie/still cameras, acoustics, side scan sonar, etc. and in addition to Fisheries research programs could be used for pipeline route surveys and/or inspections. (For further information on these three vehicles contact Dr. D.J. Scorratl - St. Andrews).

Divers

You no doubt have realized that DFE has extensive underwater programs--programs using vehicles (manned and unmanned) which tend to reduce, but not eliminate, using divers. There are many programs which could not be attempted without divers. I need not elaborate here that diving is a hazardous occupation--hence the need for careful control, competent and responsible personnel, good equipment and safety.

In DFE we have a number of full time professional divers; Jack Roe and his team at Burlington. Incidently this team also operates the T.R.O.V. 1B. They are thoroughly professional, very reliable and responsible people who have, over the last six or seven years, made a significant contribution to the Department's underwater research programmes.

DFE also has some 90 to 100 part time divers who use diving as a research tool to locate /examine /investigate biological and/or geological phenomena under water. They are research biologists, technicians, hydrographers and some ship's personnel. This very large group of people are in the main very keen to further the Department's research objectives. However, not always with a very responsible approach to diving and on many occasions conducting unsafe diving activities. We have, to date, been blessed in not having any accidents or fatalities. Most of the work is carried out in 30 feet or less--which may account for the loose attitude. Some of these people are very good, others so-so.

GUIDE FOR DIVING SAFETY

Responding to a complaint from the D.I.P.S. and to co-ordinate the variety of training the divers had, it was necessary to develop a uniform approach to safe diving operations. D.F.E. prepared the "Guide for Diving Safety". This really is a synthesis of several well known diving publications, some common sense and above all, a genuine concern for the Public Servant who dives and the employer. It is by no means perfect--hence we do get some criticism and support. It is dynamic and will change to meet requirements. However, "Safety is an attitude of mind" and no safety publication is worth the paper it is printed on unless the participants appreciate this and become involved. The DFE Guide is used by:- E.M.R.; D.I.NA..; Labour; Health and Welfare; Justice; and Treasury Board Occupational Health and Safety. It is not a best seller but does have a place in our diving activities.

These are not mutually exclusive activities--they are complementary.

RECENT ADVANCES IN DOPPLER ULTRASONIC BUBBLE DETECTION

By

Mr. B.C. Eatock, Dr. K.E. Kisman,
Mr. L. Ferrari and Mr. R.Y. Nishi

ABSTRACT

Ultrasonic detection of bubbles can provide an objective, quantitative measure of decompression stress. Most ultrasonic bubble detection instruments currently provide an audio output of the Doppler shifted return signal. However, it is frequently difficult to discriminate the transient bubble signals from the signals due to all other scatterers in the field of view of the transducer. The selectivity of the Doppler signal can be improved by range gating techniques. A Doppler unit, recently developed at DCIEM, provides this feature through phase modulation. The requirement for objectivity is met by a digital signal processor which resolves the Doppler signal into its spectral components and then automatically analyzes the signal for the occurrence of bubble transients.

INTRODUCTION

In this paper we discuss recent advances in Doppler ultrasonic bubble detection which have been made at DCIEM.

The formation of nitrogen bubbles in blood is thought to be the cause of decompression sickness. Therefore, we wish to be able to detect them:

1. to better understand the nature of decompression sickness;

2. to predict the onset of the bends before a diver feels the symptoms, for therapeutic reasons; and

3. by counting the number of bubbles which are formed during different dive profiles, to arrive at a more sensitive indicator of decompression stress than mere observation of bends symptoms.

Various groups around the world have used ultrasound to detect bubbles in blood since the early sixties (1). Ultrasound is sound at higher frequency than the audible limit, which is around 16Khz. In bubble detection, frequencies in the megahertz region are typically used.

Medical ultrasonics is a large field. In most medical applications the ultrasound is used to detect tissue structures much as a sonar echo is used to detect an underwater object. The bubble detection problem differs from most medical applications in that bubbles, as targets, are relatively small and few. In addition they are transient, that is, the bubbles are observed for only short periods of time.

These factors would seem to make the problem of detection more difficult, but they are countered by the exceptional acoustic properties of the bubbles. Bubbles are much better scatterers, or reflectors, of ultrasonic energy than liquid or solid objects of comparable dimensions. This makes their detection possible (2, 3).

PRINCIPLES OF THE DOPPLER ULTRASONIC TECHNIQUE

Although several different ultrasonic techniques have been used for bubble detection, the most popular at present seems to be the Doppler technique. Doppler instruments are commonly used in medicine to detect blood flow to search for cardiovascular abnormalities. In our application the blood flow signal constitutes a nuisance because it helps to mask the signal from bubbles if they are present (4).

With animal subjects, an ultrasonic transducer is surgically implanted around one of the animal's veins, usually the posterior vena cava. One of the transducer elements converts a radio frequency signal into an ultrasonic beam and transmits it into the vein. This beam is scattered in all directions by the objects in the blood, mostly red blood cells. Some of the scattered ultrasound is sensed by a second transducer element which produces a radio frequency signal that is then amplified in the receiver. If a bubble passes through the ultrasonic beam the signal level in the receiver increases because the bubble scatters more ultrasound. Since the targets are moving, the scattered ultrasound is slightly shifted in frequency. This is called the Doppler effect. The amount of the Doppler shift is proportional to the velocity of the scatterer. The receiver obtains a signal at the Doppler difference frequency. Since this signal is in the audio region we can listen to it and record it.

To monitor human subjects a different kind of transducer probe has to be used since it would be inconvenient to implant the transducer. The probe is held against the chest and the transducer elements are mounted at a slight angle so that their beams overlap over a fairly broad region at about the depth of the pulmonary artery, near the heart. The pulmonary artery is chosen as target because it drains the whole venous system, so any bubbles which are formed and enter the blood stream will eventually travel to this vessel. Unfortunately, with this arrangement echos are received from moving objects such as the heart and artery walls, and these add to the blood flow signal to help in masking any bubble signal that might be present. On the other

hand, since the Doppler effect is used, echoes from stationary tissue are ignored. This eliminates a large amount of clutter.

Figure I is a block diagram of the basic components required to build a Doppler unit. A stable radio frequency signal source is required. The frequency chosen is typically 5 MHz. This signal is amplified to a level of about 100 mW before being applied to the transducer.

The received signal is amplified, by a factor of at least 100. The gain requirement differs with experimental conditions. Minimum gain is required with the implanted probes and maximum gain is required for big fleshy individuals.

Next the received signal is mixed with a signal at the transmitted frequency and we obtain a signal at the Doppler difference frequency in the audio region. The Doppler signal requires further amplification and perhaps filtering. Finally an instrumentation output is provided for recording or viewing on a scope, and an audio output is provided for monitoring with headphones or a speaker.

Unfortunately, for most of us the task of picking out bubble sounds from the background signal is very difficult. The experts concede that it takes approximately a month of training to acquire the ability to distinguish bubble sounds, and even then not everyone can succeed.

This was the state of the art. Our goal has been to change that situation and two improvements have been developed.

RANGE GATING

One way to improve the Doppler signal is to use a range gating technique. This means that the range is limited so that we accept signals from between certain range limits only. That way, echoes from the heart and artery walls can be reduced.

Conceptually, the easiest way to make a range gating system is by using pulsed ultrasound. Basically, instead of producing a continuous signal the transmitter produces a pulse, which might, for example, be 5 microsec. long. At this stage the receiver is off. The pulse propagates out to the target and back. To travel 10 cm in human tissue, it takes about 66 microsec. At about the time it is expected that the pulse will return from the target the receiver is switched on for a short period of time. Different ranges can be selected by varying the delay between the transmitted pulse and the time that the receiver is switched on.

However we have found the pulse method undesirable because it reduces the overall sensitivity of the instrument. Since the transmitter is on for only a short period of time, the target scatters for only a short period of time, and the total amount of energy scattered is reduced. This makes the job of the receiver more difficult.

The method of range gating we have chosen uses phase modulation (5). The usual continuous waveform applied to the ultrasonic transducer is a sine wave. Figure 2 shows a phase modulated sine wave. Phase modulation shifts the phase of the wave by 180°, which is like flipping it about its axis. Phase modulation is illustrated here at 2 points, once when the signal is about to pass through zero, but instead starts down again, and second where it flips from minimum to maximum.

The "M-sequence" signal that is applied to produce the phase modulation is illustrated in Figure 3. Each time a transition occurs the sine wave flips. This signal is called psuedo-random because during a certain period of time it appears to be random. After that the signal repeats.

The phase modulated sine wave is transmitted, scattered, and returns to the receiver before the phase modulation pattern repeats. A delayed replica of the waveform that was used to modulate the transmitted wave is now used to demodulate the received wave. The amount of delay can be chosen to correspond with the time taken for the ultrasonic wave to travel out to the region of interest and back. In the demodulation process those signals which come from out-of-range targets are shifted away from the transmission frequency. These out-of-range signals then can be filtered out when we extract the Doppler frequency.

The phase modulation technique is not quite as selective as the pulse technique, but it has the advantage that the targets are continuously irradiated, and the scattered power is greater.

A portable phase modulated Doppler ultrasonic transceiver has been developed here for research purposes. It features selectable frequency, operation in either continuous wave or phase modulated mode, selectable gain, and two sets of independantly controlled high pass and low pass filters.

TRANSIENT SPECTRAL ANALYSIS

So far, a method has been described to reduce some of the background signal which masks the bubble signals. But we still need a way to detect and count the bubbles automatically. For this purpose an interesting transient spectral analysis technique has been devised (4, 6,). The bubble signals carry three kinds of information that may help to distinguish them from background: amplitude, frequency, and time duration. If typical frequency limits for bubble signals are compared with those for other signal sources, there is unfortunately a large overlap, because the bubbles have a wide range of velocities

and therefore contribute a wide range of Doppler frequencies. So we can't use a simple filter to discriminate them.

Things look better, however, if the comparison is made for a single bubble over a short period of time, say about 10 msec. That is how long it takes the bubble to pass through the field of view of a transducer. Then it appears that the frequency content of the bubble is fairly well defined. This suggests that a kind of transient filter could be used.

If the typical time duration of a bubble event is compared with the time that other sources contribute to the signal, the bubble events really do look like transients. While listening to the Doppler signals it can be noticed, that they sound almost periodic. In spectral analysis, we look at the frequency content of the signal as the signal changes in time. For a periodic signal, the frequency content is constant in time. For an almost periodic signal the frequency content is almost constant in time. But, if we superimpose a transient signal onto an almost periodic signal, we will notice a big change in frequency content at the time of the transient. This is easy to search for and it can be done automatically (4, 6,).

The equipment used to implement this technique is illustrated in Figure 4 (4). The spectral analysis is performed by a macro-arithmetic processor which is essentially a very fast computer, having many processors in parallel. The recorded data are digitized and fed into the MAP at a rate 32 times slower than the recording rate. The data are divided into segments, each 10 ms. long and for each segment power spectra are computed using a technique known as the Fast Fourier Transform. Then an automatic comparison is made with preceding and succeeding segments to see if a transient was present. In effect the constant parts of the power spectra are subtracted out, so only the changes remain.

To operate the MAP, a host computer, a PDP 11/10 is required along with various peripherals.

Figure 5a is a Doppler signal as it would appear on a scope, with a big transient in the middle. After application of the spectral analysis technique the signal appears as in 5(b) (4). The background signal has almost disappeared. The computer checks to see whether or not the transient signal exceeds certain limits before it is counted as a bubble. Figure 6 shows how the technique can be used for a quantitative analysis of a dive. A French minipig was subjected to the dive shown in the upper left corner, down to a depth of about 90 metres and back up all in a time of about 5 minutes. The experiment was performed by the French (7), but the signal was analyzed at DCIEM. The heights of bars represent the number of bubble events counted in 10 second intervals. This is the most quantitative and objective analysis of a Doppler signal that we know of. It suggests that we can

count bubble signals as a method to evaluate the hazards of a given dive profile and should lead to safer dive schedules.

In conclusion, we have shown that it is difficult to detect bubble signals using the conventional Doppler technique, because of a large background signal. However the level of the background signal can be reduced using a range gating technique and an instrument incorporating this feature has been developed. Automatic detection and counting of bubble signals is possible using transient spectral analysis.

The range gating technique is inexpensive and can be included in field Doppler units. Spectral analysis is expensive at the present time, but if the current pace of advancement in digital electronics continues, within a few years it will become possible to use the spectral analysis technique in real time, and secondly equipment costs will drop to the point where the technique can become an invaluable laboratory tool, and perhaps eventually a field tool.

Returning to the three objectives mentioned at the outset: We are now in a better position to understand the nature of decompression sickness and, using the improved Doppler technique for monitoring experimental dives, arrive at safer dive schedules. If the instrument gets wide enough distribution in the future, it will also meet the goal of being a useful diagnostic and therapeutic aid.

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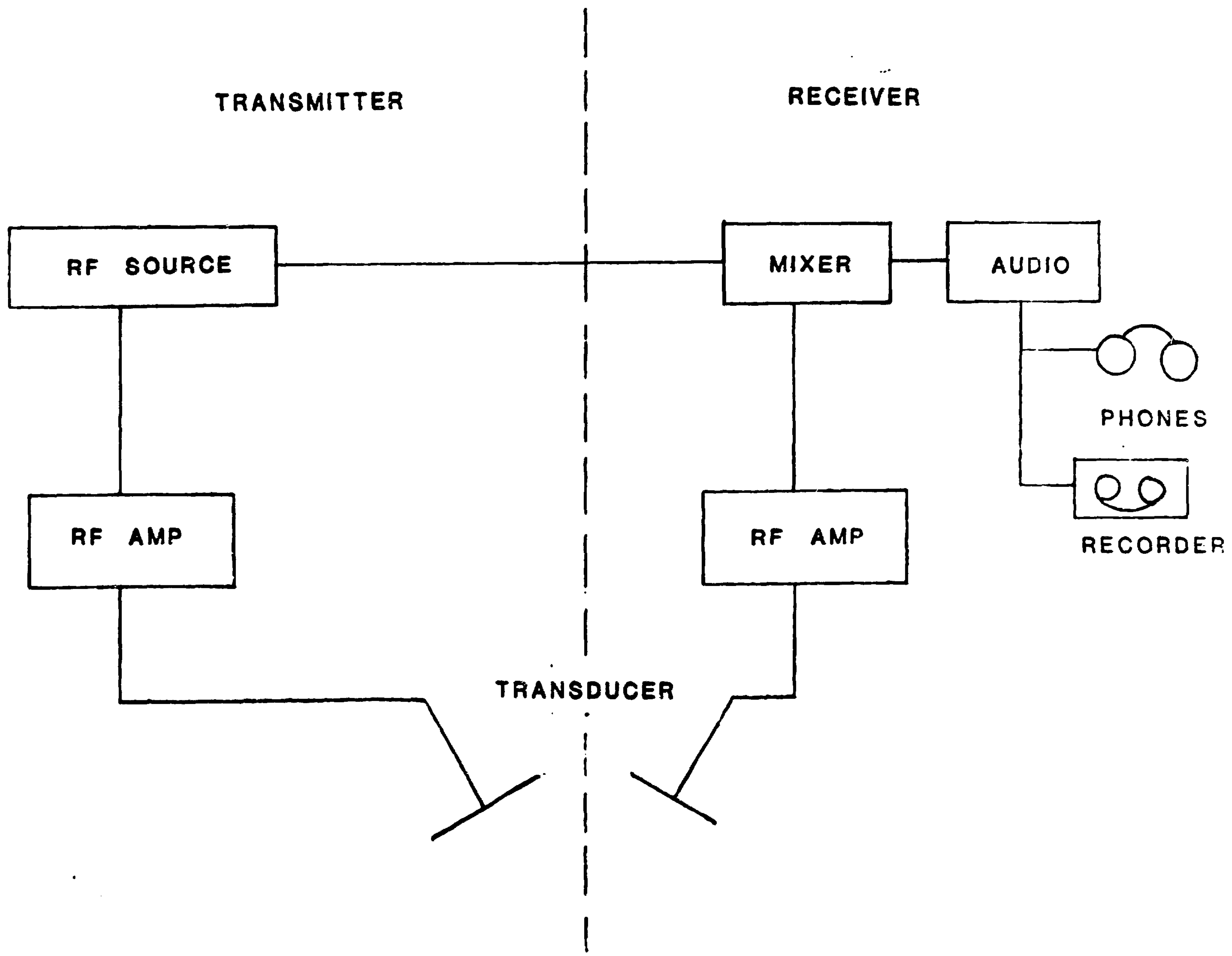
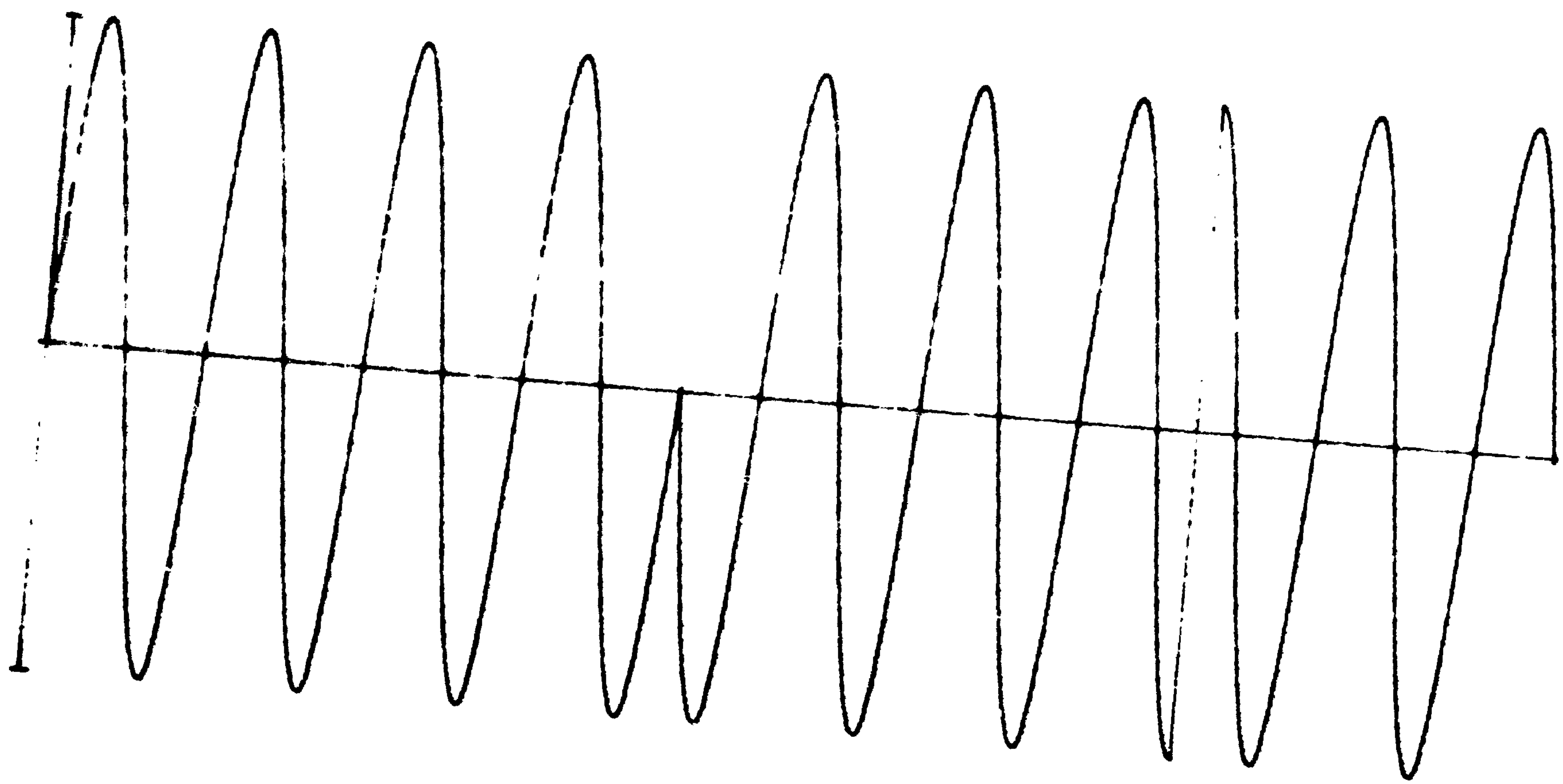
6. Kisman, K.E. Decompression Bubble Analysis. DCIEM Report No. 75-R-1078, Jan. 1975

7. Guillerm, R. et al Medsub Hyp IO 50, 1973

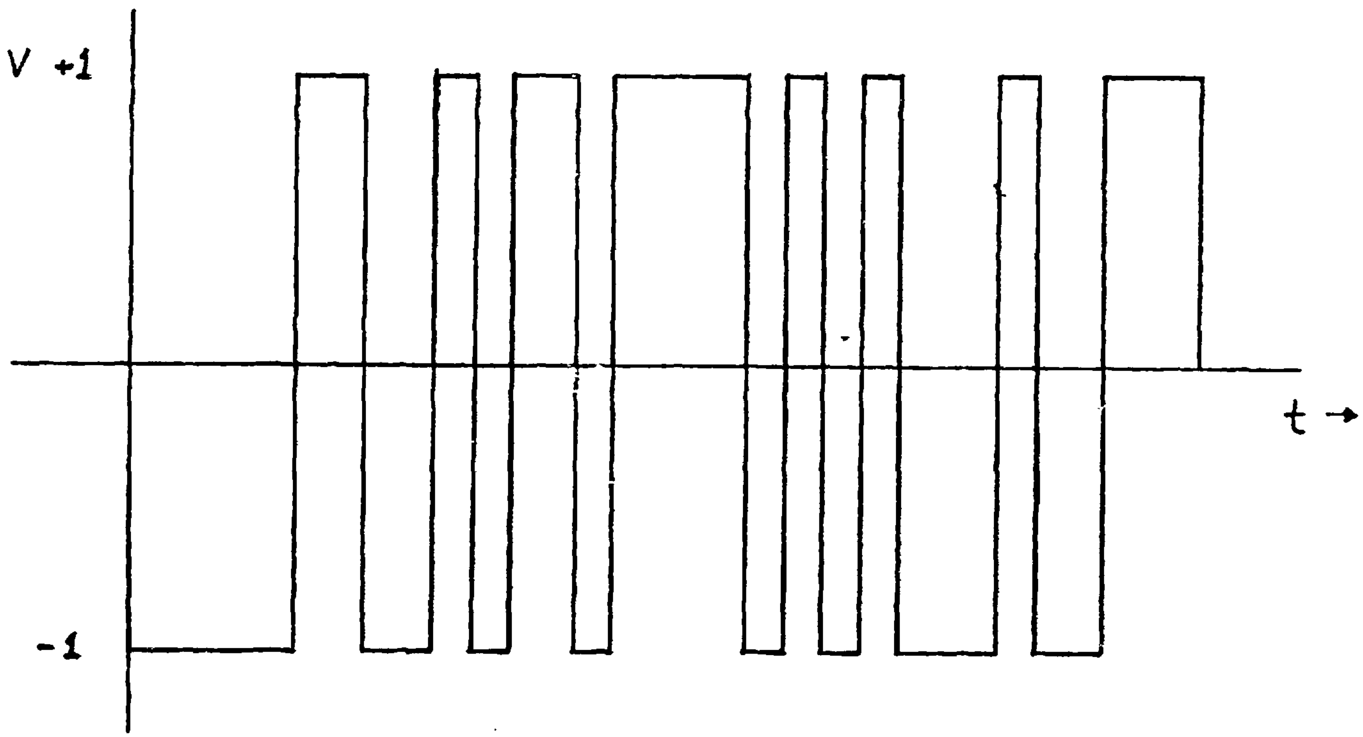
FIGURES

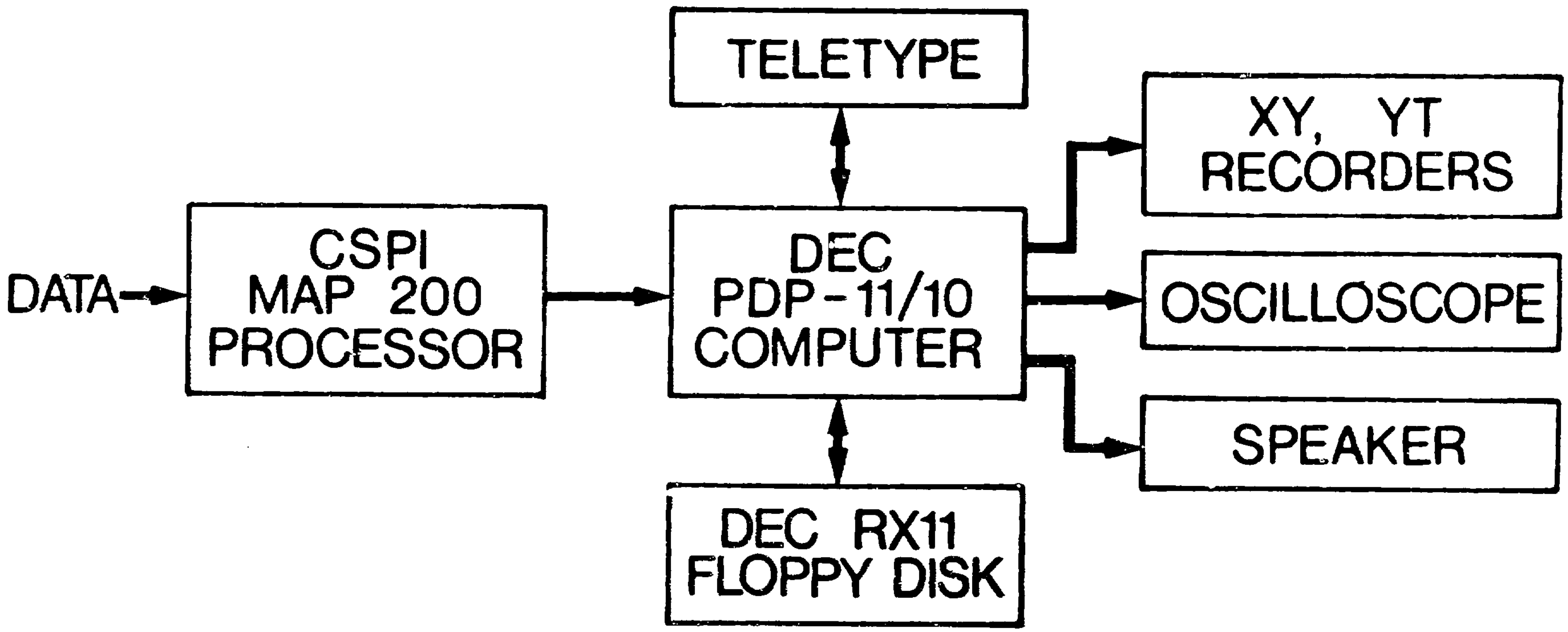

TRANSMITTER
RECEIVER
RF SOURCE
MIXER
AUDIO
PHONES
RECORDER
RF AMP
RF AMP
TRANSDUCER

PHASE MODULATED SINE WAVE



M-SEQUENCE SIGNAL





4. Configuration of signal processor used for transient spectral analysis.

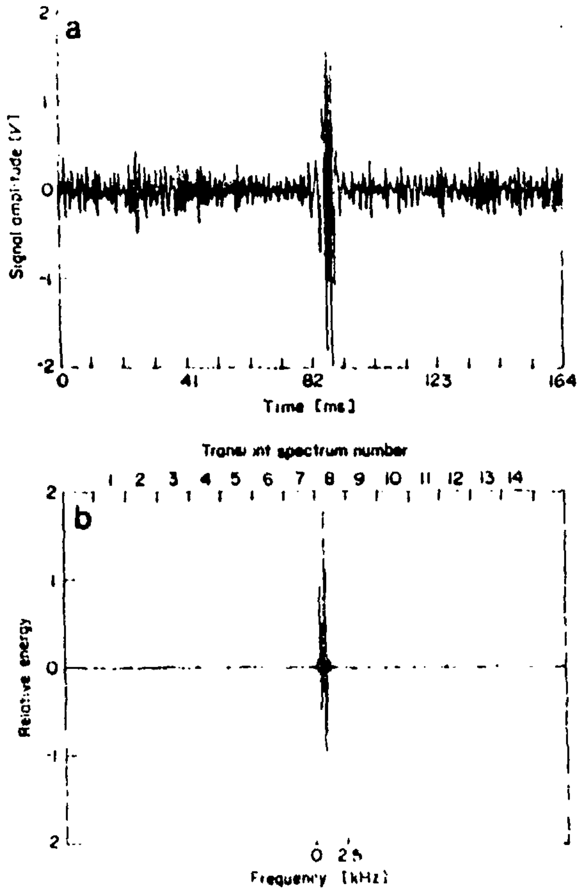
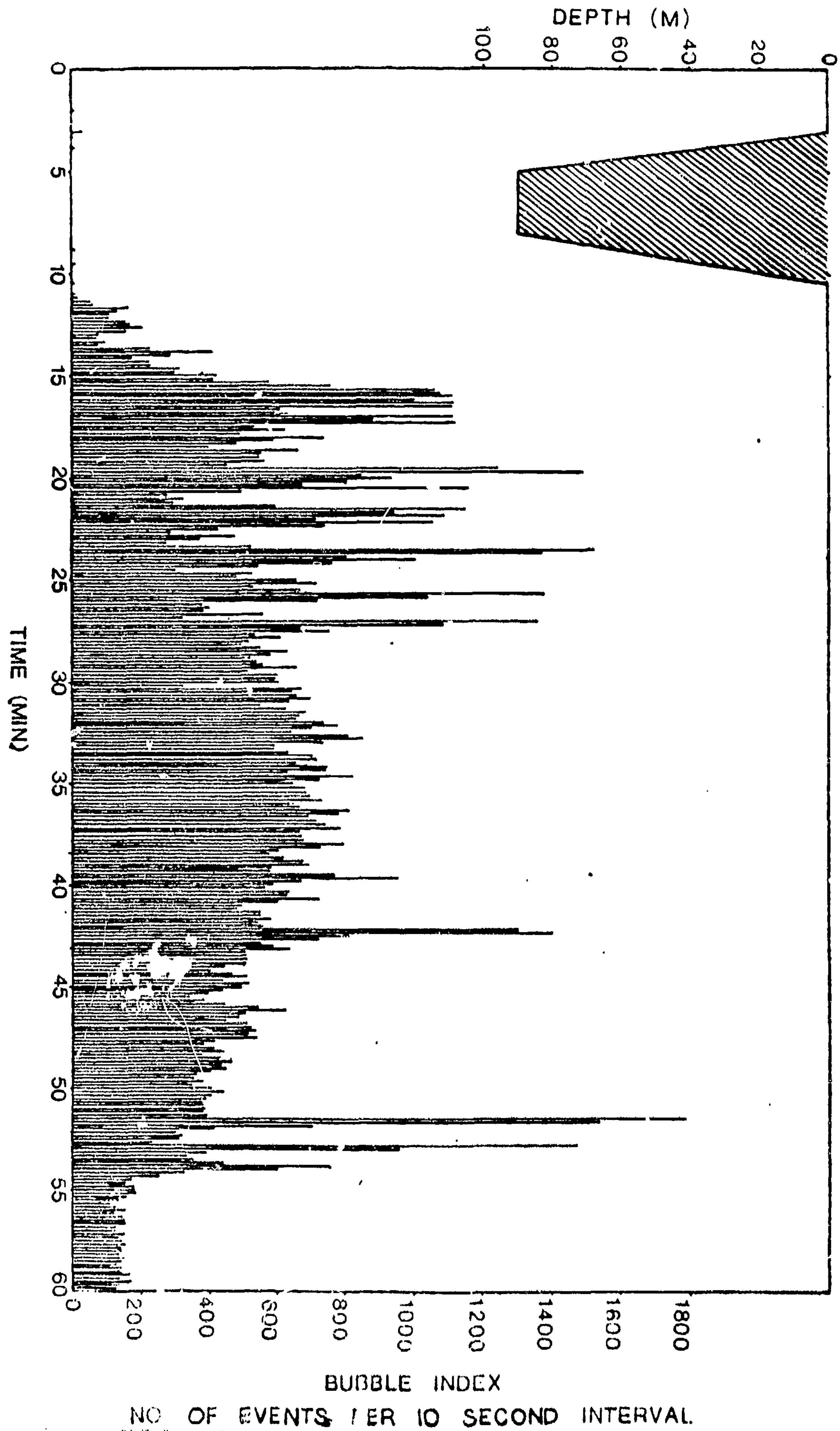


Fig. 5 a– Doppler ultrasonic data obtained during decompression from the posterior vena cava of a rabbit. There is one bubble transient present with a signal/noise ratio of 4:1; b–Transient spectra of the data block shown in a. There are 14 spectra each containing 32 spectral components over the frequency range 0–2.6 kHz. The signal/noise ratio of the bubble transient has increased to 36:1.

Kc.t 4


DEPTH (M)
100
80
60
40
20
0
TIME (MIN)
0
5
10
15
20
25
30
35
40
45
50
55
60
0
200
400
600
800
1000
1200
1400
1600
1800
BUBBLE INDEX
NO. OF EVENTS PER 10 SECOND INTERVAL

GUIDELINES FOR MIXED INERT GAS DECOMPRESSION

By

Mr. Tikuisis and Dr. L. Kuehn

ABSTRACT

An ideal tissue model is used to present the theory of inert gas exchange in the body under hyperbaric conditions. Multiple gas switching is examined and criteria are established for the state of optimal decompression, that is, minimizing the total inert gas tension and thereby reducing the chances of bubble formation. The most effective method for decreasing the total decompression time is found by switching from an inert gas of small half-time to an inert gas of large half-time at some determined time prior to decompression. A multi-tissue model with a variety of different half-times is also examined with emphasis placed on the safe decompression of slow tissues.

INTRODUCTION

Our objective regarding mixed gas decompression is to present a method of minimizing the total decompression time by switching gases without compromising the safety of the diver. Although gas switching is not a new development, the approach taken here is to switch gases while at bottom prior to decompression. In this presentation, we first wish to outline the theory behind gas switching, then to show that multiple gas switching for both saturation and sub-saturation diving prior to decompression leads to a reduced total decompression time.

Decompression sickness or the "bends" is believed to be the consequence of the formation of gas bubbles in a diver's body during ascent. These gas bubbles arise whenever boddy tissues and fluids become super-saturated with the inert gas of the breathing mixture. Safe decompression is achieved by minimizing the total amount of gas dissolved in the body. Different inert gases have different rates of uptake and elimination in the various tissues of the body. For example, N_2 is generally considered to be slower compared to He. We can take advantage of this phenomena by selectively switching gases in order to minimize the total amount of dissolved gas at the start of decompression.

An example of gas switching from a 'fast' gas, namely Gas 1 in Figure 1, to a slow gas (Gas 2) without changing the ambient pressure shows that a minimum total gas tension is achieved followed by a slow rise back to saturation pressure. We propose that for a safe and faster decompression, the minimum point of the total gas tension profile be taken as the optimal choice for the start of decompression.

Multiple Gas Switching

The effect of multiple gas switching, i.e, switching more than once with different gases, has been analyzed graphically. It turns out

that the combination leading to the greatest reduction of the total gas tension is achieved by switching from the fastest gas available to the slowest gas available.

Figure 2 illustrates a comparison between binary and ternary gas switching. In both the saturation and sub-saturation profiles, the binary case yielded a greater reduction in total gas tension as compared to the ternary case.

Using this result, we concentrate our efforts towards calculating the time of switching prior to decompression that would yield the lowest total gas tension at the start of decompression for binary systems. Such a calculation has been performed for the binary system of switching from He to N_2.* The result is shown in Figure 3 by the solid curve where the horizontal axis gives the bottom time and the vertical axis gives the time of switching such that the total gas tension reaches a minimum at the start of decompression.

Multi-Tissue Model

Up till now, we have considered only a single tissue. Different tissues will have different rates of uptake and elimination for the same inert gas. We make this distinction by assigning half-time values for the inert gases to the various tissues. These half-time values are an index of the rate of gas uptake and elimination. The smaller the half-time of the tissue, the faster it is.

It is desirable to minimize the total gas tension in the tissue of most physiological significance with respect to damage due to bubble formation. First we examine the multi-tissue model for the case of sub-saturation.

Figure 4 illustrates the sub-saturation case for two different exposures and the resulting total gas tension upon switching from He to N_2. For a relatively short exposure time, the fastest tissue, namely tissue 1, determines the optimal switching time. It can be clearly seen that at the point of switching, the gas tensions in the slower tissues have not built up appreciably. Therefore, the minimum point in the gas tension profile marks the optimal onset for decompression. However, for a longer exposure, an intersection of the gas tension profiles of the various tissues occurs. The start of decompression at the minimum point of the gas tension profile of tissue 1 is no longer acceptable due to the high gas tension remaining in tissue 2. Allowing for tissue 2 to reach a minimum for decompression may not entirely be practical since the faster tissue regains gas tensions very quickly. As a compromise, the intersection of tissues 1 and 2 would appear to be the optimal point for the beginning of decompression.

For very long exposures, that is, when essentially all tissues become saturated, priority should be given to the slowest tissues for two reasons. First, physiologically, it is believed that gas bubble formation in slow tissues such as fat and bone lead to severe damage.

* $t_{1/2}$ (He) = $t_{1/2}(N_2)$, based on molecular masses

This is especially important since such gas bubble formation is not easily detected and may have long term effects. Second, physically, the slow tissues become the controlling factors during decompression; therefore, it would be efficient to minimize the gas tensions in the slow tissues prior to decompression. Although saturation would be reached by tissues 1 and 2 in this case (see Figure 5), this is not considered a disadvantage since the half-times are such that the gas tensions in tissues 3 and 4 would decrease rapidly during decompression. Based on the reasons given, the intersections of tissues 3 and 4 would appear to be the optimal point for the beginning of decompression.

Application

The benefit of this gas switching theory can be better appreciated by relating the results to an existing decompression table. The restriction imposed on the choice of table is that the half-times for different inert gases be clearly distinguished for each tissue or compartment. The half-times of inert gas uptake and elimination for tissues of varying perfusion rates and fat content given by Schreiner fulfill this requirement. The safe ascent criteria is adopted from the 16-compartment German model by Ruff and Muller* for the gases He and N_2. Figure 6 gives the total decompression times for four gas systems for a 15 metre saturation dive. The reduction of the decompression time by switching prior to decompression is highly significant.

SUMMARY

The theory of gas switching as presented here has been based largely on physical considerations. Furthermore, the results given were derived theoretically and have not been validated experimentally. The advantages of gas switching can only be met with a tissue model whose half-times for different gases are distinguished for the different tissues.

At certain depths, gas switching may invoke certain physiological problems. To counteract this and still retain the benefits of gas switching, various gas mixtures may be applied. For example, in order to avoid nitrogen narcosis, it may be necessary to switch from a heliox mixture to one containing N_2 below the narcosis level with heliox as the balance.

In conclusion, gas switching theory has demonstrated that switching prior to decompression can significantly reduce the total decompression time for both saturation and sub-saturation diving. We have also seen that switching more than once is unnecessary. In a practical situation, switching from heliox to N_2 O_2 not only may reduce total decompression time but it also introduces a more comfortable and perhaps a more economical decompression. Application of the theory to existing dive tables is a subject of further research.

* S. Ruff and K.G. Muller, Experimentelle and Theoretische Untersuchung des Druck Fall Problems; Deutsche Luft und Raumfahrt, Forschungsbericht 71-48, July, 1971.

FIGURE CAPTIONS

1. An example of gas switching from a fast gas (Gas 1) to a slow gas (Gas 2) without change of ambient pressure. Minimum total gas tension is achieved followed by a slow rise back to saturation pressure. The vertical axis denotes a tissue gas pressure relative to the saturation pressure while the horizontal axis denotes time in normalized units.

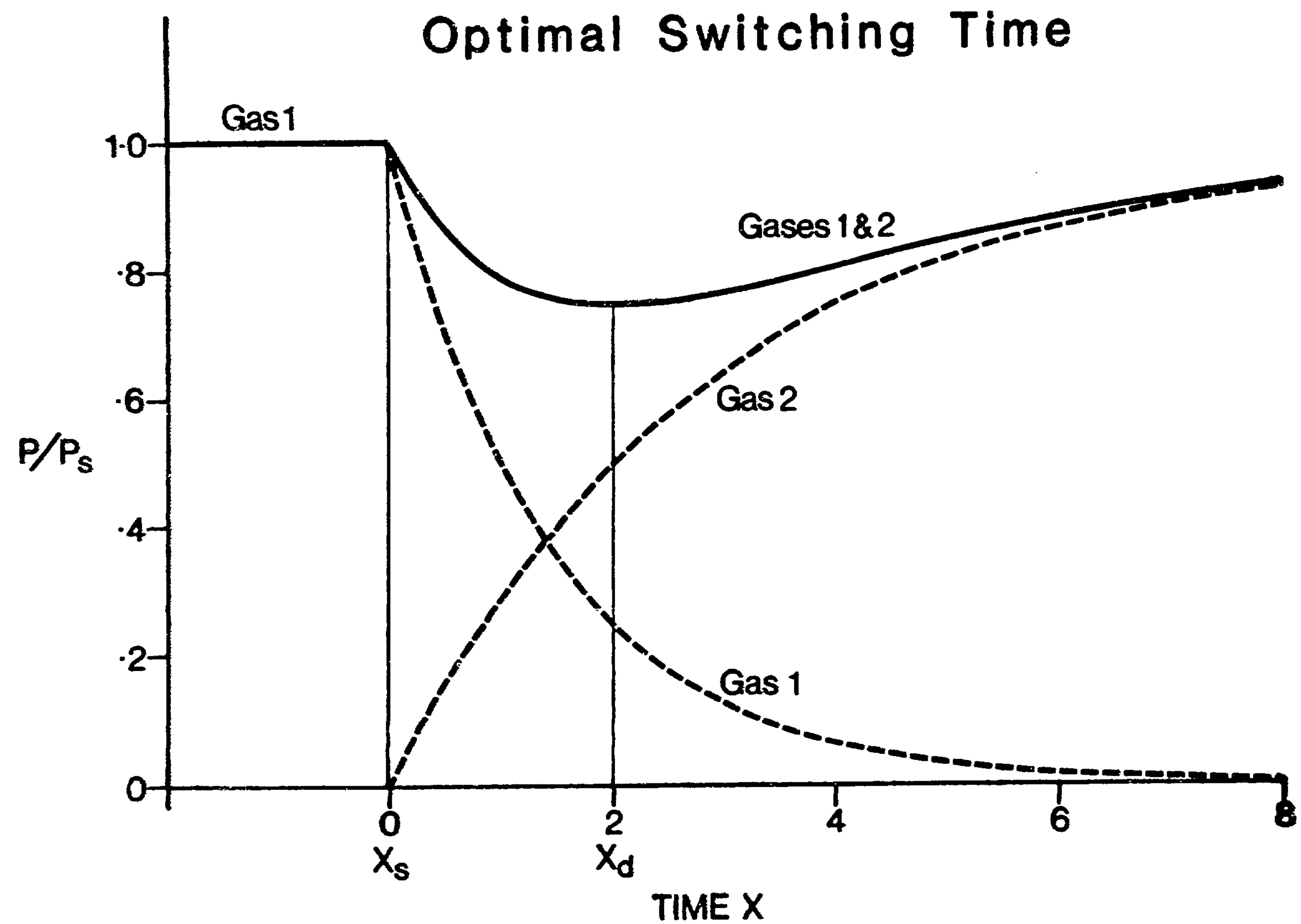
2. Comparison between binary and ternary gas switching in the saturation and subsaturation cases. The vertical axis denotes a tissue gas pressure relative to the saturation pressure while the horizontal axis denotes time in normalized units.

3. Graph of binary gas switching time (that would yield lowest total gas tension at start of decompression) versus time at bottom. Both times are expressed in normalized units.

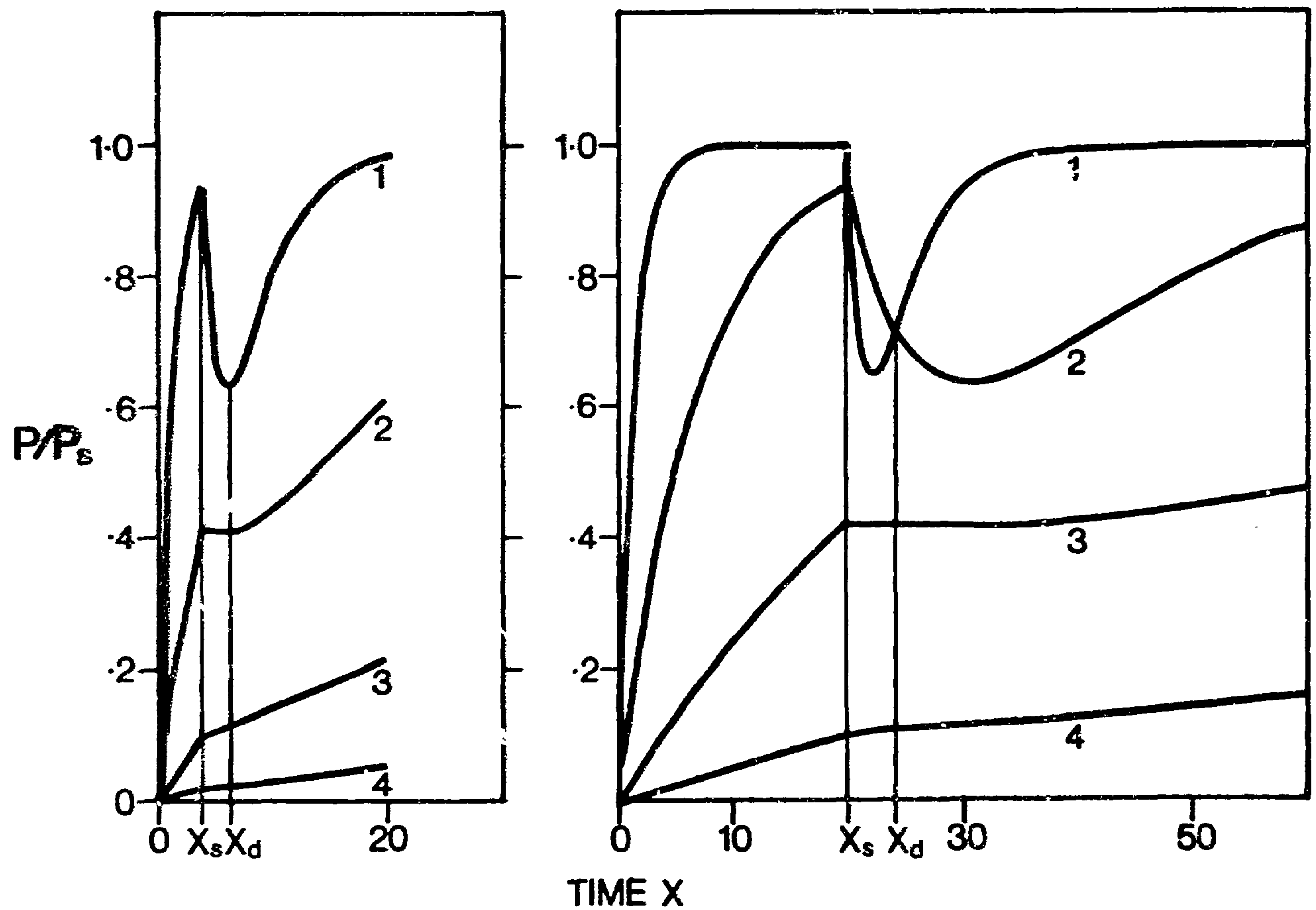
4. Display of optimal gas switching for two different subsaturation exposures of a 4-tissue model. The vertical axis denotes tissue gas pressures relative to the saturation pressure while the horizontal axis denotes time in normalized units.

5. Display of optimal gas switching for a saturation exposure of a 4-tissue model. The vertical axis denotes tissue gas pressures relative to the saturation pressure while the horizontal axis denotes time in normalized units.

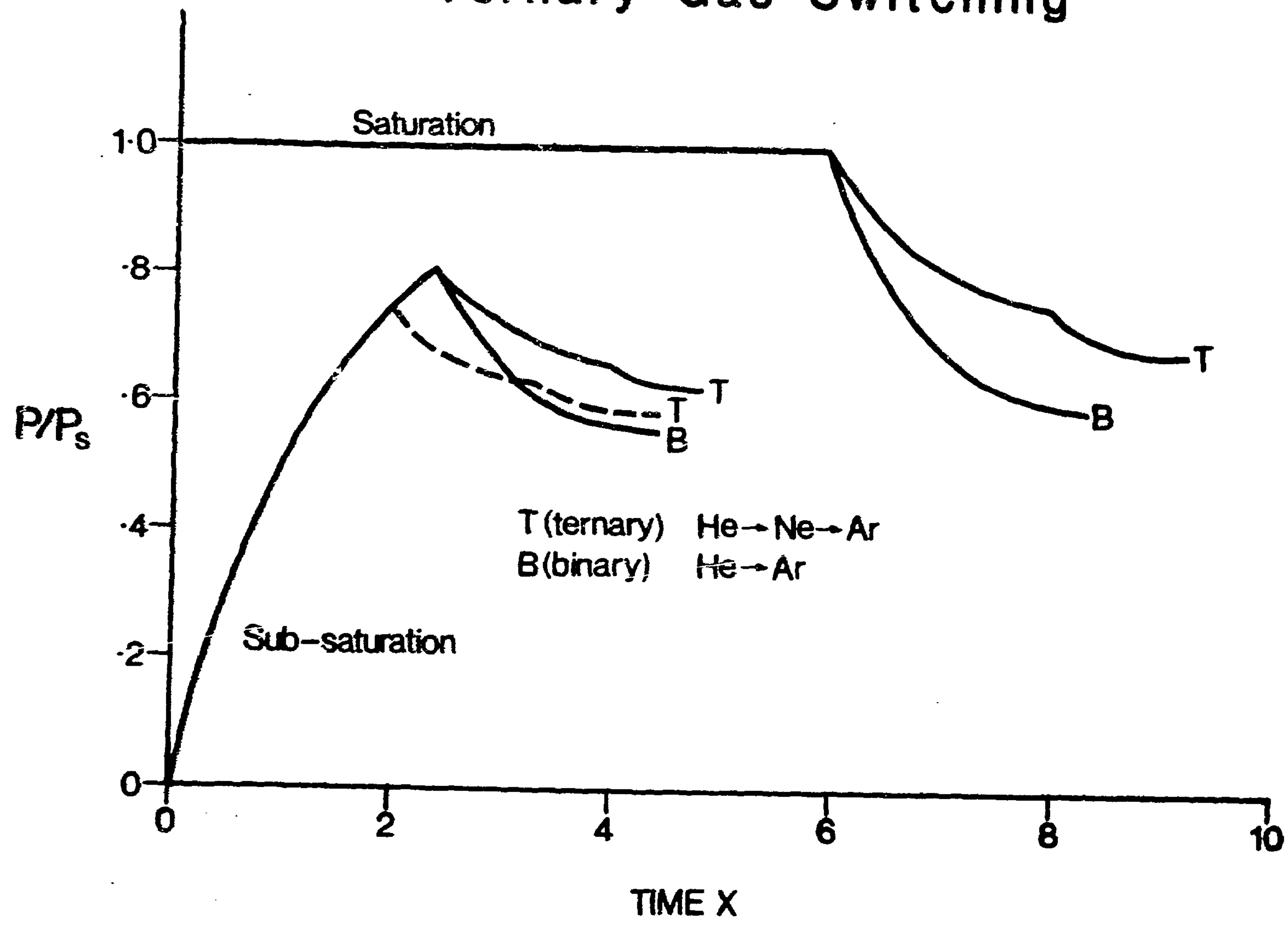
6. Display of total saturation decompression times based on a 16-compartment model of Ruff and Muller for various cases of gas switching.

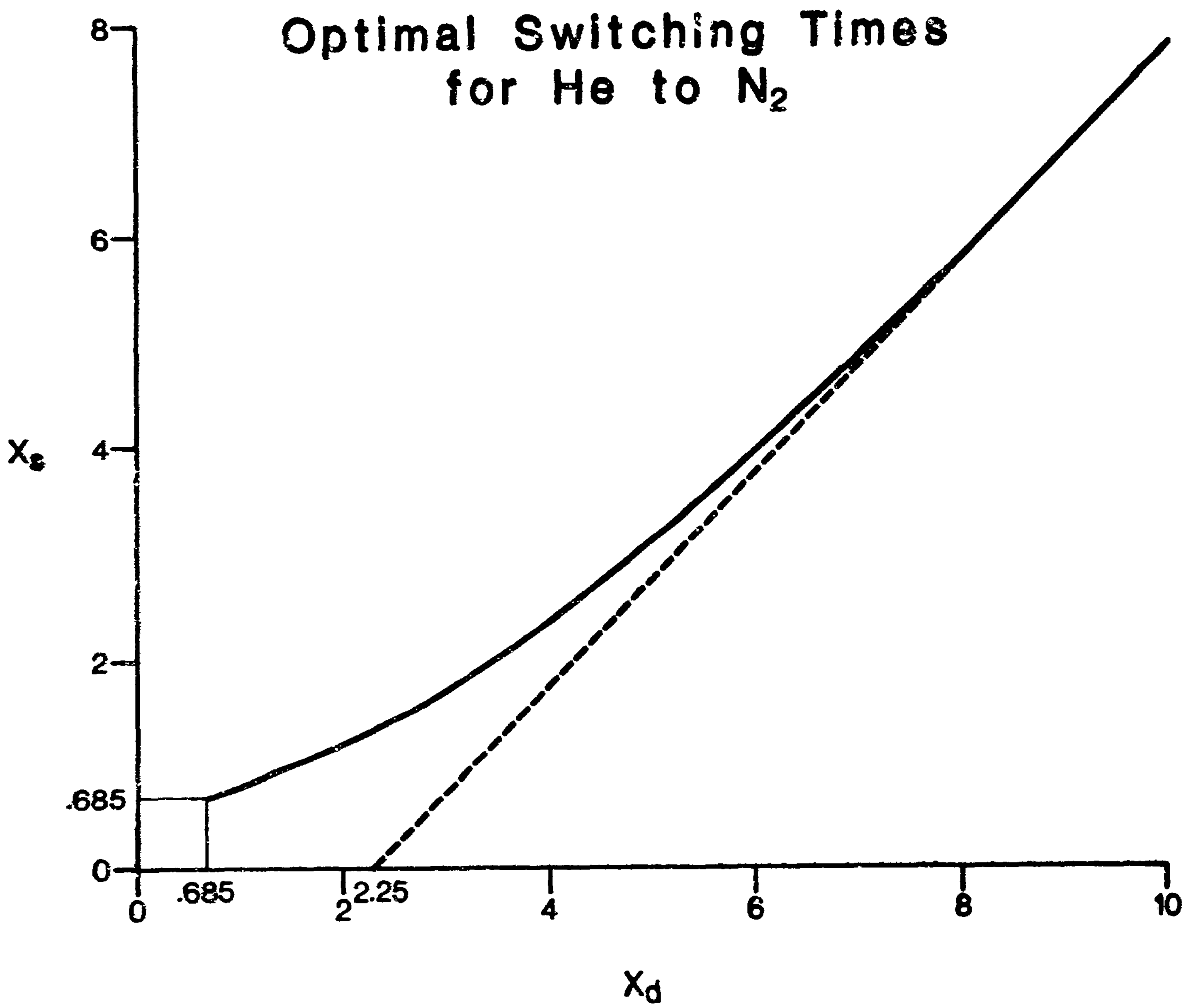

Optimal Switching Time
Gas 1
Gases 1 & 2
Gas 2
Gas 1
P/Ps
1·0
·8
·6
·4
·2
0
0
Xs
2
Xd
4
6
8
TIME X

Optimal Switching Times for Four Tissues under Sub-Saturation He to N_2

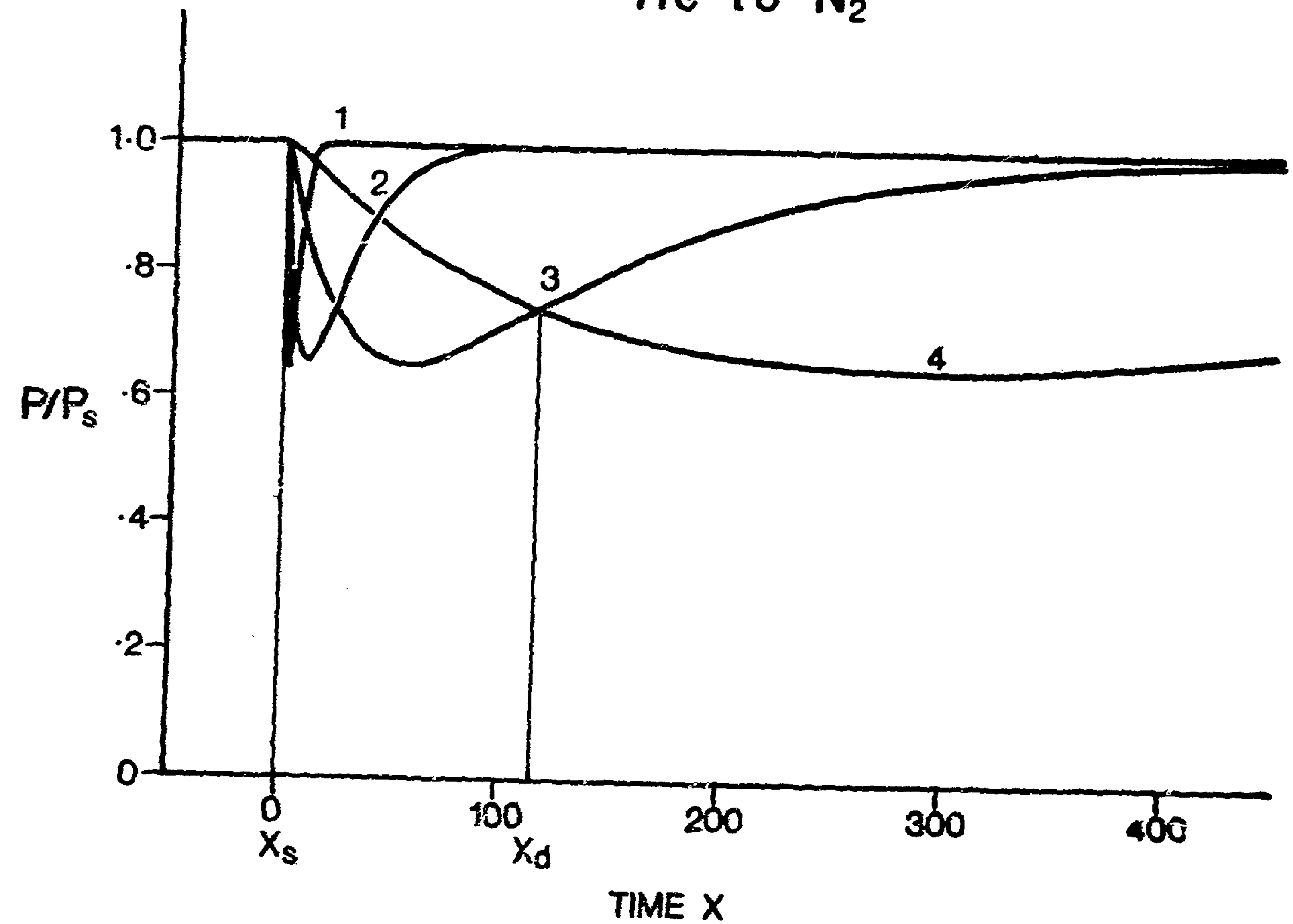


Comparison between Binary and Ternary Gas Switching




Optimal Switching Times
for He to N_2
X_s
8
6
4
2
.685
0
0
.685
2
2.25
4
6
8
10
X_d

Optimal Switching Times for Four Tissues under Saturation He to N_2



Total Decompression Time from Saturation based on the 16-Compartment Model of Ruff and Muller.

Depth	15 m
PO_2	0.21 ata
Decompression stops	10 min

Inert Gas System	Total Decompression Time
He only	4.8 hrs
N_2 only	14.2 hrs
He to N_2 at start of decompression	2.5 hrs
He to N_2 at 60 min prior to decompression	1.8 hrs

BREATHING SIMULATOR AND ITS USES FOR EQUIPMENT TESTING

by

J.J. Grodski, Ph.D.

INTRODUCTION

The DCIEM's breathing simulator was built in 1975 and since then, it has been used for testing a variety of diver's life support equipment. The purpose, advantages and uses of the simulator are reviewed in this paper on the basis of the available range of the operational parameters and typical measured quantities. This is followed with an indication of DCIEM's future aims in this area.

THE PURPOSE AND ADVANTAGES OF BREATHING SIMULATORS

The general purpose of breathing machines is to provide means for a continuous, fully controlled simulation of the major features of man's breathing.

The breathing simulator provides major advantages in testing and evaluation of diving breathing equipment. While manned testing of life-support equipment is mandatory, it is cumbersome when objective evaluation is required due to the non-uniformity and variability in man's breathing. The machine, however, provides means for equipment testing under controlled and non-variable conditions. Additionally, application of the simulator eliminates the need for use of human subjects in most of the objective testing, inherently eliminating the numerous disadvantages associated with frequent and lengthy human diving. On the other hand, a typical breathing machine is designed to simulate only some of the multiple aspects of the breathing process thereby limiting its application to specific kinds of tests.

THE DCIEM MACHINE

The DCIEM machine was designed specifically for diving equipment test and evaluation. It encompasses a few novel features incorporated into its design and it provides a full range of adjustment on a number of parameters. This development stimulated some industrial and naval diving testing and evaluation establishments of a few countries to plan acquisition or to acquire simulators of similar design.

The DCIEM simulator was designed for operation externally to the hyperbaric chamber with which it is interfaced. This drastically reduces hazards and allows an easy access to controls, permitting readjustments during the testing process. The machine is capable of simulating the breathing process at pressures from atmospheric up to 5000 fsw (2225 psig) when interfaced to the DDF. Currently, the machine is interfaced to a 1000 fsw hyperbaric chamber; in this configuration, the pressure rating of the chamber constitutes the pressure limit. Additionally, the simulator was designed to provide means for control of the following parameters.

Tidal Volume - (volume of a breath) may be preselected anywhere between 0.7 to 4.0 litres.

Breathing Rate - may be preselected anywhere between 5-70 breathes per minute.

Wave Shape - is basically sinusoidal, however it may be altered through the use of 12 separate velocity controls affecting 12 corresponding segments of the breathing cycle.

Inhalation-to-Exhalation Time Ratio - may be preselected anywhere between 0.8 and 1.2.

Exhaled Gas Humidity - is simulated by passing the inhaled gas through water and buffles in a bubble chamber.

Exhaled Gas Temperature - is controlled through the use of heaters on the bubble chamber and the exhale line.

CO_2 addition - may be used at a rate of 0-4 litres per minute at standard conditions (slpm), limited to the depth of 1000 fsw in the present design.

Oxygen Consumption - is the single, major physiological aspect of breathing which the machine is not capable to simulate.

APPLICATIONS

The simulator constitutes a vital tool for objective testing of a variety of breathing apparatus. The majority of its applications at DCIEM pertain to underwater breathing equipment such as:

a. SCUBA - single hose;

b. SCUBA - double hose;

c. Band Mask - open circuit and demand;

d. Helmet - open circuit or demand;

e. Helmet - recirculating;

f. UBA - semi-closed circuit; and

g. UBA - closed circuit.

The interfacing of the tested equipment to the simulator varies depending on the equipment tested and the aim of the particular test. For example, when testing a helmet, an appropriate mannequin is required; when testing a SCUBA equipment, mating of appropriate pipes may be sufficient. However, connections forming the breathing channel must be free of leaks in all cases; otherwise, tests performed on the equipment result in erroneous data.

The simulator may be useful also in other work such as e.g., testing of CO_2 scrubbers for a submersible.

Concerning interpretation of test and evaluation data, it must be recognized that data obtained from tests on one set of breathing equipment of a particular brand should never be generalized to be TOTALLY representative of the brand. Differences between individual sets have been frequently shown to be significant. For that reason, a good evaluation program should include more than one test sample.

MEASURED QUANTITIES

Parameters measured in typical tests involving the simulator include: variety of differential pressures (e.g. across the mouth, across the wall of the hyperbaric chamber), respiratory flow rate, and tidal volume (displacement of the piston in the simulator).

Particular attention is paid to an accurate determination of the external work of breathing; the latter is expected to form the major acceptance criterion in future respiratory equipment evaluations. Calculation of the external work of breathing requires integration of a real-time data acquired from the experimental assembly. A fast digital data acquisition system was assembled and programmed for that purpose.

With additional equipment one may also monitor inspired PCO_2, CO_2 levels at various points in a helmet, gas consumption, sound levels, and other parameters which may be required.

FUTURE DEVELOPMENTS

A mass spectrometer is being acquired. It will provide the means for monitoring static and breath-by-breath variations in a breathing gas composition. Additionally, a temperature control system for the bath in which the tested equipment is submerged is planned to be installed. This feature is of particular relevance to our testing programs pertaining to the use of diving equipment in climatic conditions typical in Canada.

CONCLUSIONS

In conclusion, it is stipulated that a consistent, high quality, objective evaluation of diving breathing equipment requires the use of a breathing simulator capable of providing the full range of testing parameters, simulating the breathing process in as many details as the present technology allows.

THE ATMOSPHERIC DIVING SYSTEM; "JIM"

BY

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The concept of providing a pressure resistant exoskeleton that will allow useful work at great depths, without incurring decompression penalties, is as old as diving technology itself.

Articulated diving armour has traditionally been regarded as somewhat of an impractical curiosity and any attempts to sell the concept has met with skepticism and a general air of "do some useful work on a cost-effective basis at great depth - then we'll talk about it". Most of the attempts to design and build such systems have foundered in this sea of cynicism and the concepts are rarely realized in operational hardware.

The downfall of many attempts from the turn of the century right up to contemporary designs is basically one of concept rather than design. Most one atmosphere "afficionados" see their particular system as an end-all, be-all, rather than simply one of a number of tools and gadgets to allow effective work in the ocean.

The history of successful diving firms have shown that the ability to do work on the sea floor is hardly a guarantee of success, but rather a basic ingredient in a long and complex recipe. One atmosphere systems have been used with some success even with the limited technology available in the past, but only on the following basis:

a. the users had a specific job to carry out with a guarantee of a pay-off if the work was accomplished (market);

b. the work was too deep or required too long a bottom time for conventional diving techniques (specific requirement);

c. The one atmosphere system was used as an adjunct to a host of other proven techniques rather than and end unto itself (used as a tool).

Although the advantages of a one-atmosphere suit system seem very obvious, research into this facet of diving technology has lagged far behind the general research and application of conventional ambient pressure diving. The basic reasons are simple: The majority of previous attempts to produce a working, one-atmosphere suit have failed while the efforts to increase the depth range of ambient pressure divers have been successful.

The requirements for routine deep diving are comparatively recent. With the advent and financial impetus of the offshore petroleum exploration industry, diving techniques and equipment that were barely past the most basic experimental stages were hurriedly pressed into service to take advantage of a market that commercial diving firms had long dreamed about. This frenzy to dive deeper and stay longer reached it's peak in the late sixties and "secret decompression tables" and wan, white-faced divers were the order of the day. The ocean frenzy of the sixties was certainly not limited to small diving companies - a number of major firms in the U.S. and Europe held their noses and leapt into a strange ocean that promised much and gave little. In a decade of earnings - conscious conglomerates, the word was simply that "if you weren't into the Ocean "biz", you would be left behind." The fallacy of that approach has been cruelly borne out by the number of expensive submersibles rusting on the shelf and the long list of small, innovative companies, with catchy space-age names, that left only small bubbles behind to mark their downward progress into the ocean business. The current decade has marked a reassessment of the whole situation by several major diving firms. These companies, with a commendable degree of vision, quietly told their salesmen to stop selling technology that didn't yet exist, reviewed their existing commitments and buckled down to the hard research required to put their divers down to the worksite and bring them back safely.

Sophisticated techniques and expensive saturation equipment took the place of "bounce dives" and the depth and time limitations of simple diving equipment were backed up into the shallower regions where they belonged. Competitive diving firms who would scarcely talk to one another in the past, for fear of betraying some proprietary secrets, began to cooperate and pool their hard-won research data, in the interests of safety.

The oil companies, the ultimate client for these deep diving services, encouraged and aided these realistic efforts. These same clients had been considerably sobered by the number of diving fatalities and near fatalities in the oil field and they no longer accepted blithe assurances that deep-diving is a "piece of cake". From all of this, several facts emerged. There were few or any "secrets" after all. Putting a diver down several hundreds of feet and bringing him back safely on a routine basis, was expensive and time consuming. There was simply no safe way around it. Proper training, massive, expensive hardware, and conservative techniques gave the ambient pressure diver at least a fighting chance, but there was still a significant element of every-day danger and no one could really predict the long range effects.

This long-winded dissertation has little to do with the subject of this paper other than to set the scene and show why the hitherto neglected one-atmosphere and remote controlled systems suddenly found themselves under serious review. Most of the current technological and physiological problems centre around the exposure to pressure and the need to keep the diver alive, and well, in cold, hostile environment. If the effects of extreme pressure, temperature and submergence in a liquid can be overcome, most of the problems are solved. Surely, self-evident - but the trick is to do it and still be left with a system that can accomplish the basic tasks required of it. Efforts in this direction run the gamut from remote controlled vehicles with manipulators to manned submersibles with complex tactile feed-back work systems.

Most of these devices work surprisingly well, but are expensive, complex and have task limitations. They do not offer a pancea for the replacement of man-in-sea, at this time. The one-atmosphere suit system cannot offer a direct replacement for the ambient pressure diver but presents a distinct capability envelope that covers a significant percentage of today's deep water tasks.

Enter "JIM"

Personalizing the ADS by giving it the name "JIM" was done somewhat tongue-in-cheek by DHB Construction Ltd., although it was meant as a genuine tribute to "Pop Peress's" first test diver, Jim Jarrett.

A problem, more physiological than technical, is the fact that the suit gets all the credit rather than the operator. The press seldom say, "John Doe, wearing an ADS, set a new depth record", but "Jim sets new record"--very demoralizing for the operator!

Another problem that arose is a familiar one in the aeronautics or aerospace industry. From "JIM's" progeny sprang names "JIM 2", "SAM 1", "SAM 2", "WASP 1" and with it the difficulty of determining precisely what model is being discussed.

ADS Terminology

Basically, the ADS is discussed in-house, using the following terminology:

a. Type 1 (JIM) - The original prototype "JIM" utilizing a cast magnesium alloy body.

b. Type 2 (JIM) - A modified version of the Type 1, but using the same material for the body castings.

c. Type 3 (SAM) - Sam is a smaller, more compact version of JIM and uses a fabricated aluminum body and a re-configured joint system.

d. Type 4 (SAM) - SAM 4 is a redesign of SAM 3 using a fibreglass body shell.

e. WASP - A mid-water unit using thrusters and a tubular lower body section rather than articulated legs.

Type Description

Type 1 (JIM) - The original "JIM" prototype is not used operationally but serves as a design-change and accessory test platform in the Alton Plant.

Type 2 (JIM) - The type 2 is the configuration most familiar to the public because of extensive press and trade journal coverage. The type 2 has a body section of cast magnesium alloy with operator entry through a hinged head dome. The limbs utilize a patented semi-sphere joint system originally designed by "Pop" Peress and further modified by UMEL designer, Mike Humphries. The joints use a fluid bearing and allow flexion extension as well as rotation. The elbow and hand pods, the boots and the leg spacers are made of both magnesium alloy and glass reinforced plastic. Vision is through four optically-ground ports in the head dome section.

Type 3 (SAM) - The type 3 SAM is a somewhat smaller version of JIM and has its operator entry through a hinged mid section. The body is fabricated of aluminum rather than magnesium alloy which results in a reduction of depth rating but allows a much shorter building time and a drastically decreased post-dive schedule. A major change from JIM is the limb system. The type 3 limb uses a joint design, perfected by Mike Humphries that allows a significant increase in the articulation range with a decrease in physical size. Although the type 3 joint is essentially a modification of the currently patented type 2 joint, it is different enough to be the subject of an additional series of pending patents.

The operator's viewing system is also altered and a single semispherical port replaces the four port system in the type 2 JIM. The hand manipulators have been re-designed from the original parallel-jaw grip to an opposed digit manipulator that allows angular deflection as well as rotation, relative to the hand pod. It should be noted that all the manipulators have been designed to fit any ADS in the series so that no particular manipulator is standard to a suit type, but rather can be fitted for either general use or specific

task functions. These changes on the type 3 SAM ADS result in a more compact unit that closely follows the lines of the human body. Wearing the type 3, the operator feels more "man-in-sea" than 'n the JIM unit and the increased mobility heightens the effect.

Type 4 (SAM) - SAM 4 is essentially the same as the type 3, but has a body shell fabricated from a high density re-inforced plastic material. The result of this change will be to increase the rated working depth to a level even greater than the original JIM systems as well as virtually eliminate the troublesome post dive maintenance. Because of the materials used in the JIM series, corrosion has always been a serious potential problem. Avoidance of this problem has entailed rigid specifications on coating materials and applications as well as a routine post dive inspection of virtually every square inch of the suit surface. The non-metallic type 4 will not require the same rigorous post dive procedures.

WASP - The WASP is a new-comer to the ADS Service line and essentially comprises a standard ADS upper body and vision dome system with a tubular lower body. T e unit is fitted with rotateable thrusters and "flys" in a manner similar to the most maneouvreable of the current crop of small manned submersibles. The unit is fitted with the type 3 SAM arms and manipulators. Since WASP is not as widely known as "JIM", it may be appropriate to discuss the design and working concept in some detail.

The WASP unit may be viewed as a hybird between a very small submersible and the standard ADS articulated system. WASP is designed to work at depths up to 2,000 feet and receives power for its thrusters through a small diameter surface umbilical. A unique feature is the on-board battery system which acts as a buffer to allow spurts of full power that the umbilical would not be capable of supplying. In addition, the battery system acts as a safety device in that it provides for self-contained operation for nearly one hour, should the umbilical be severed. The umbilical can be detached from inside the WASP and the operator can surface using thruster power, or make a buoyant ascent by jettisoning ballast.

The WASP unit can alter buoyancy and altitude and is able to assume virtually any position by use of the rotating thrusters. Since the operator has his arms occupied during work tasks, the unit is designed to be controlled by foot pedal motions similar to those used in driving a motor vehicle.

WASP was designed by Graham Hawke, an engineer who worked extensively with the JIM systems.

The internal instrumentation monitoring, and life support systems are similar for all the ADS series and basically comprise:

a. Life support

b. Communications

c. Monitoring

d. Emergency systems

The life support systems used in the ADS series are passive, lung powered units. The operator simply breathes through an oral-nasal mask which is ducted to a set of CO_2 absorbent cannisters mounted in the back of the body shell. Make-up O_2 is stored in 3000 PSI cylinders outside the suit and meter oxygen through a mechanical dome-load regulator. When the internal pressure falls inside the suit due to the operator metabolizing the oxygen, the sealed portion of the regulator expands and adds O_2 to bring the cabin pressure back to one atmosphere.

The life support system is so simple as to appear almost primitive. In this era of solid state electronic control units and fuel cell sensors, and a vast array of shelf-available life support gear, the simplicity of the life support system used in the ADS causes some eyebrows to be raised. We have designed and built life support gear for use in the ADS, that fully represents state-of-the-art systems. We are reluctant to retro-fit these into the suits, however, until long-term testing has convinced us beyond a doubt that the same degree of reliability that we currently have, can be achieved. Use of an electronically controlled system would eliminate the annoyance of the oral-nasal mask, but would introduce a host of failure-potential components.

Communications are handled with a dual system. Primary communication is accomplished by a hard wire system running down the tether wire. This is the same simple, rugged system used by surface supplied ambient pressure all over the world. Back-up is provided by a self-contained wireless communication system that can be utilized, should the tether wire become severed.

Internal instrumentation is also simple: direct readouts are provided for internal cabin pressure relative to one atmosphere, depth in feet of sea water externally, cabin temperature and partial pressure of O_2. Secondary readings indicate life support O_2 pressure, elapsed time, external battery condition, and the operator is provided with a hand light to inspect all internal assemblies in dark water.

The emergency systems for the ADS are comprised partially of hardware and partially of procedural concept.

On the hardware side, the ADS is fitted with outside weights that can be separated and dropped allowing the ADS to make a buoyant ascent. Should tether umbilical entanglement preclude ascent, the umbilical may be detached from inside the suit, as previously mentioned, the ADS is fitted with a back-up wireless communication system that allows bottom surface communications should the umbilical be severed.

Other safety considerations include a pressure operated strobe light that begins flashing when the ADS is within a few feet of the surface. This ensures rapid location should a buoyant ascent be made.

Also supplied is a pinger that would allow quick location should the ADS become stuck on the sea floor or ascend under ice, for example.

The best single safety device is procedural. It is simply the operator's policy not to allow use of the ADS beyond on-site ambient pressure diving capability, unless a second ADS and operator is on site, ready for immediate deployment should it be required.

While on the topic of safety, some mention should be made of the fail-safe characteristics of the ADS joints. Perhaps the most common question asked about the ADS is "what would happen if it leaks?" Laymen and even some who should know better, picture such catastrophic possibilities as the operator being cut to pieces by high pressure sprays of water or having the suit fill up completely in the twinkling of an eye!

Because of the nature of the joints employed, the joint seals have a two-fold purpose. They keep the water out of the suit and retain a captured fluid that acts as a support bearing. Should a seal leak, the bearing will be lost and the joint will be forced together by the outside water pressure. This will immobilize or "freeze" that particular joint, but will at the same time, prevent the entry of any water.

Other life support and emergency devices have been under development and testing and will be fitted to the ADS units as they reach a plateau of reliability from testing. This would include such things as a surface-supplied life support umbilical on a ADS-to-ADS pluggable umbilical, that can be plugged into a trapped ADS on the bottom. Another useful device would be a simple means of active heating for the diver in an emergency situation.

Emergency Situations

An example of a typical emergency situation with the ADS occurred this year in the North Sea. After a routine inspection dive in approximately 500 feet of water, the ADS was being recovered onboard the support, when the tether umbilical became mechanically severed. The ADS plunged back to the sea floor and a few seconds later, the operator came on the wireless communication unit and laconically reported that he "was on the bottom and awaiting instructions". The support vessel was hurriedly moved clear and stood by

ready to pick him up. Upon being informed that the vessel was clear, the ADS operator dropped his weights and ascended to the surface, where he floated, strobe light flashing, until he was secured to a new load line and taken aboard. At no time did either the ADS operator or the surface crew feel that they were in the middle of a dire emergency.

The best illustration of the inherent safety of the ADS unit lies in what measures were not required but could have been taken had they been required. If the decision had been made not to ascend by dropping weights, a weighted shot line with a "fire-fly" strobe light could have been lowered to the location indicated by the pinger receiver. The ADS operator could have locked his manipulators onto this recovery line and because the whole unit only weighs 40 odd pounds in the water, he could be pulled up by hand if necessary. Failing this, the second ADS would have been deployed carrying a short snap line and the two ADS' raised together. The shirt-sleeve environment and the long life support capability changes in emergency diving situations from the "knee-jerk" reflexes required in ambient pressure diving to a situation that can be examined for the most simple, logical solution, with a number of alternatives to be chosen from.

To Conclude

It is my personal conviction that the atmospheric diving system is here to stay. Although it provides only one of a number of alternatives to ambient pressure diving in its particular capability envelope, it's a good alternative. Unless a major technological breakthrough in ambient pressure diving occurs, such as Dr. J. Kylstra's liquid breathing experiments becoming a functional reality, you can plan to see and hear a lot more about the ADS in the future. I have been associated with deep ambient pressure diving virtually all of my adult life and it is a particular thrill to me to watch the ADS operator climb out of the suit after a 1000-foot, six-hour bottom time dive. Standing on the deck with a cup of coffee and a cigarette and discussing the dive is a most refreshing alternate to eight days of saturation decompression.

TAURUS SUBMERSIBLE

By

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ABSTRACT

General acceptance of submersibles as useful industry tools has led to the development of the New Generation Submersible (NGS). One such NGS is described. It has all the inspection and manipulator abilities of earlier vessels with the added capability of diver lock-out, transfer under pressure and dry transfer into one-atmosphere subsea chambers. The NGS measures 34 ft. length, 13 ft beam, 12 ft. height and weighs 53,000 lbs. Payload is in excess of 2 tons and depth rating is to 1100 ft. This submersible was launched on 7 February, 1977 and after sea trials is planned to be exhibited at the OTC before entering service in the Gulf of Mexico.

INTRODUCTION

The pressure on offshore petroleum operators to extend production into deeper water has necessitated the introduction of equipment and techniques that would not have found a place in the industry ten years ago. This trend towards what some engineers may still think of as 'space technology' will likely continue as exploration and production areas push out to the edges of the continental shelves and beyond into the steeply descending continental slope. Ways that have proved sufficient in previous years will be superseded by more complex systems but there is no reason to believe that the new methods will be any less reliable than the old nor that they will not also, in due course, become standard procedures.

A typical example of this evolutionary process is to be found in the underwater service industry. For more than a hundred years the needs of engineers have been met by various versions of the hard hat diver. The introduction of self-contained underwater breathing apparatus (SCUBA) towards the end of World War II freed the diver of his cumbersome and often dangerous umbilical gas supply hoses but did little to improve his mobility over long distances or his capability to work in great depths.

Only in the last ten years has there appeared a significant improvement in this field, due to the introduction of the commercial submersible, a small vessel similar to the military submarine but without the ability to charge its own batteries. The removel of the diesel

engine charging and propulsion systems found on submarines have allowed submersibles to achieve great economies in size and weight albeit at the expense of autonomy. These savings are translated into reduced crews and operating costs together with enhanced manoeuverability and depth capacity. Windows have been added and mechanical arms supplied to carry out simple tasks. For the first time, customers and engineers untrained in diving methods could be carried to the seabed to inspect problem areas and work in progress. Television recording systems proved particularly suitable for use with these vehicles so that even when a customer is unwilling to ride in the submersible, rapid and factual information is made available to him of conditions in areas hitherto considered the private domain of the trained diver. That this new device did not initially receive the wholehearted support of the diving operators is hardly surprising. This prejudice, coupled with a not unnatural industry inertia towards accepting new methods, has been a major factor in hampering the development of the commercial submersible service industry, however it must also be stated that a few of the very early examples of this new technology fell far short of the target in both safety and reliability aspects as well as in the areas of payload and versatility. Most of the first generation submersibles, however, have performed well and are playing an important role in deepwater construction projects, particularly in the area of pipeline and marine platform inspection in the North Sea, to the extent that it is presently estimated that there are more than a dozen of these vessels available in this area alone.

Based on the acceptance by the petroleum industry of the usefulness of this tool, submersible engineers have been sufficiently encouraged to return to the drawing boards and produce new designs with the prime objective of serving the offshore industry - the result a new generation of submersibles (NGS). The first of this type has recently been launched and is the subject of this paper. By the time of the 1977 OTC it will have completed sea trials enabling this author to present some film documentation. It is also planned to have this NGS available for inspection close to the conference rooms in the Astrohall.

The NGS has been designed with a view to expanding the range of work that can be undertaken by a single unit. This is important because increased versatility is reflected in enhanced utilization which in turn may be passed on to the customer as a reduction in day rates. Nothing is more expensive to hire than a very specialized machine that spends most of its time idle. For this reason, it has been made capable of diver support and dry transfer as well as the more traditional tasks of inspection and manipulation. These capabilities will be addressed in the following separate sections.

GENERAL SERVICE CONSIDERATIONS

Addressing the traditional role of the submersible first, it has become apparent that, whereas great depth capability has not proved as important as was first thought, payload and endurance are of definite significance. For this reason, the depth capability of the first NGS has been limited to 1100 ft. which leave a comfortable margin for future work in support of offshore construction projects. However, the basic design would be suitable for depths up to 2000 ft. if the pressure hulls were to be fabricated from high tensile steels. (HY100/HY80 or similar). The pressure hulls for the prototype are of A516 Grade 7 material (ASTM carbon steel) and include a command chamber having a cylindrical length of 80 inches, and a diameter of 72 inches. The cylinder is internally ring stiffened and closed with hemispherical ends. At the forward end, a 36 inch aperture acrylic view window is employed giving a greatly improved visibility over the traditional multiple ports of a smaller diameter. Large acrylic view windows have become standard in most new designs of submersibles due to the pioneer work done on this subject by engineers of the U.S.N. Undersea Center, San Diego. The command chamber is accessed by a 24 inch I.D. conning tower (removable for air transportation) which is fitted with 5 inch diameter viewports to allow an all-round view while surfaced. The conning tower is of sufficient height to prevent ingress of small waves in the event that it should be necessary to open the hatch while running awash.

The increased space afforded by the large command chamber of the NGS allows the installation of more control and navigation equipment than in the past, this includes a full size gyro-compass, auto-pilot equipment, pinger-receiver, search-sonar, underwater telephone system and illuminated circuit display panels indicating the mode of operation of subsystems such as ballast pumping and blowing equipment. The remaining space can be utilized for mission related equipment such as video-tape recording machines, side scan sonar recorders and underwater navigation position plotters. Space not occupied by equipment is available for crew accommodation which is such in the NGS that two crews can be carried. This is important because in the earlier designs the most common reason for breaking off from working is crew fatigue. Where a relief crew can be accommodated, the wasteful process of return to surface and recovery on board the support ship, every 8 hours, is avoided.

Endurance achieved by a relief crew must be matched by increased battery capacity so that trips to the surface for battery charging are also minimized. The NGS is fitted with quick change battery packs having a total capacity of 1000 ampere hours at 120 volts (8 hour rate). The lead acid cells are enclosed in g.r.p. battery boxes which are oil-filled and pressure compensated. A fork lift arrangement is supplied which is clamped to the side of the submersible to facilitate removal of discharged batteries and their replacement with freshly charged packs. This changeout system is expected to significantly reduce turn-around time at the surface.

Manoeuvrability and propulsion power are important in submersible operations but until recently, most submersibles have been limited to one or two propellors. The NGS is fitted with a total of 5 thrusters, each of 5 h.p. The thrusters are fitted with "Kort" type nozzles and have stepless speed control from full ahead, through stop, to full astern. Two are situated at the stern and can be rotated in a horizontal plane from port through center to starboard (180°). Two are situated on the sides (one port and one starboard) and can be trained in a vertical plane from vertically up through astern to vertically down (180°). One bow thruster is also provided. This is mounted on the foredeck and can be rotated 360° in a horizontal plane. The combined thrust with all motors operating in the same direction exceeds 1,000 lbs.

The payload of conventional submersibles has often fallen short of expectations to the extent that, in some designs, very little more than the weight of the crew can be supported. With the requirement to conduct more complex missions at the seabed, there is an increased demand for carrying capacity. The NGS has a payload in excess of 4,000 lbs. with a full compliment of batteries. This has been achieved without the use of syntactic foam. Additional payload on short duration dives can readily be achieved by removal of some of the battery packs.

The frame of the NGS is constructed from aluminum tubes. The tubes are closed and pressure resistant beyond the depth rating of the submersible. It has been calculated that the frame is almost neutrally buoyant in sea water. The frame has a single point lifting-eye located aft of the conning tower. The lower frame is connected to two aluminum skids through torsion type shock absorbers which have been designed to absorb accelerations up to 2g without damaging the submersible. Rubber fenders are used on the extremities of the NGS to reduce the possibility of damage if handled roughly during launch and recovery. The fenders are attached to supports in such a way that collapse is progressive, in order to preserve the integrity of the pressure hulls.

Avoidance of snagging on objects and ropes is vital to the safety of submersibles which are likely to be working on construction sites. Experience has shown that a great deal of junk may be expected in these areas. Ropes are particularly dangerous since they may be drawn into propellors and wound up to such an extent that unwinding is impossible. The almost universal use nowadays of synthetic cordage has increased this problem as these materials do not rot and are frequently buoyant so that such ropes remain for years and stand upright in the path of the submersible. A few of the conventional submersible designs are propelled by motors located inside the pressure

hull so the propellor shafts must be of substantial strength and pass through the hull in a gland seal. In this case, little can be done by the crew to release the fouled propellor. The NGS has been arranged so that every thruster can be ejected, allowing the submersible to swim free. This is possible because the thruster motors are located externally. Each motor support is held by a split clamp which can be opened by a hydraulic ram. When this is done, the thruster drops away. The power cable to the thruster is guillotined by the first inch of movement of the ram as it opens the support clamp. The claws at the ends of the manipulators can be jettisoned in a similar manner in case they are trapped. Great care has been taken to enclose all projecting machinery inside free-flooding g.r.p. fairings to prevent snagging as well as to reduce turbulence while moving through the water.

In case of unscheduled delays in surfacing the NGS carries sufficient oxygen and carbon-dioxide absorbent to allow up to 500 man-hours of life support (i.e. with two men on board, more than 10 days). Emergency breathing gear is also supplied in the form of self-contained re-breathers.

Since rapid response to call out is usually important to the customer and because keeping submersibles on standby can be an expensive business, a submersible should be air transportable. When considering the limitations that this will place on the design, a type of aircraft that is available to commercial clients must be chosen. Thus, whereas a C-5A may be used to fly a Navy D.S.R.V. this would be unlikely to be available to the offshore oilman. For this reason, the NGS, despite its large size, has been designed to be transportable in a C-130 ("Hercules"). This airplane is readily available worldwide and has a short landing and take-off capability on smaller airstrips. In order to allow this, the conning tower and side thrusters are removable reducing both the beam and height to 8'-6". Similarly, the weight for air transport can be reduced from the standard 53,000 lbs. to 45,000 lbs.

DIVER LOCKOUT

The ability of some first generation submersibles to lockout divers has been demonstrated but, in the opinion of the author, this capacity has been somewhat marginal in terms of diver heating and gas supply.

The quantity of breathing mixture consumed by divers is proportional to both exertion and depth but the latter variable is by far the most significant factor. Thus, the quantity of gas consumed by one diver at 200 metres (660 ft.) would be sufficient for 20 divers, carrying out the same tasks, at 10 metres (33 ft.) or, putting it another way, for a given quantity of gas a diver working at 200 metres can stay under pressure for one twentieth of the time that he could work at 10 metres. It can be seen therefore, that very large gas storage is required for deep diving. The NGS has a gas storage

capacity of 12,000 standard cubic ft. This is contained in three 48 inch diameter spheres housed in the tail of the submersible. The spheres are constructed from HY100 steel and are rated at a maximum working pressure of 2100 psi.

Diver heating problems become more severe with increase of depth due to the high heat conductivity of the helium employed in deep diving gas mixtures. Heated diving suits become a "must" and these consume much electrical power which in the case of a free swimming submersible can only be supplied from batteries. Some recent improvements in electrically heated suits show promise of reducing power consumption but, due to some unfortunate incidents where malfunction has caused the diver to be locally excessively heated (!) these units have not received universal acceptance. Consequently, the hot water heated diving suit is most popular but is very wasteful of energy. The only solution at present is large battery capacity and the 120 KW hours available from the NGS batteries is a significant step in the right direction.

In general, the use of a submersible as a diver transport vehicle has many advantages over the diving bell. Divers, pilots and customer representatives can travel in comfort together to the work site where an unhurried reconnaisance of the work can take place. All concerned can discuss the requirements of the task, viewing the job from many angles and consulting with persons on the surface by means of the sonar telephone system. Preliminary work to prepare the site for the divers may be possible using the submersible's manipulators (clearing debris etc.) All this can be done without pressurizing the divers. When it is apparent that only divers can achieve the next stage of the work, these men can enter the lockout chamber and pressure-up to exit the vehicle. The lockout chamber (or transfer sphere) of the NGS is accessed from the command chamber by a 27 inch diameter hatch which incorporates a 5 inch diameter viewport. The chamber itself is an 84 inch diameter sphere and is fitted with two lower hatches. The inner (uppermost) hatch is elliptical with a 35.5 inch minor and 38 inch major axis. This hatch is arranged to contain internal pressure during transfer under pressure (T.U.P.) operations. The outer hatch is circular, with a 38 inch diameter opening. This hatch will withstand external pressure and is fitted with a downward looking 2 inch diameter viewport.

When the divers are ready to exit the chamber, the submersible lowers an anchor weight and ballasts up off the bottom to afford maximum head room for the divers to move out. Subsequent work can be viewed by the customers, pilots and the diving supervisor by means of the 36 inch diameter forward view window. Assistance with heavy work can be rendered using the submersible's manipulator arms.

After the dive, the divers re-enter the lockout chamber closing both hatches and are carried to the surface under pressure to be either transferred under pressure into deck decompression chambers (DDCs) or alternatively decompressed in the lockout chamber

itself. In order to facilitate connection to DDCs, the NGS is fitted with a lower skirt, furthermore the suspension system of the support skids is supplied with a hydraulic ram which can compress the suspension so as to cause the NGS to "squat" downwards approximately three inches to close the gap between the skirt and the trunkway into the DDCs.

DRY TRANSFER INTO ONE ATMOSPHERE SUBSEA CHAMBERS

The most novel function of the NGS is its ability to travel to the seabed and "dock" on top of subsea chambers (SSCs) in order to effect dry transfer of workmen between the submersible and the chambers. This is a one atmosphere and "shirt sleeve" operation by which it is meant that the personnel involved are at no time subjected to pressures in excess of one atmosphere absolute (i.e. normal sea level pressure) nor are they required to wear other than normal work clothing. The NGS "docking" procedure has some similarity to that used in space during the "Apollo" program and proceeds as follows.

The NGS pilots and oilfield workers enter the submersible while it is on the deck of the surface support ship (SSS) which is cruising in the general area of the target SSC. The position of the chamber has been established approximately by reference to surface navigation systems (satellite or other) and possibly confirmed by interrogation of a transponder located on the SSC or by sidescan sonar. After closing all hatches and carrying out pre-dive checks the NGS is launched down an inclined ramp, travelling down on its launch cradle until lifted clear by its own buoyancy. During the launch the captain of the SSS sets a course to best reduce ship movement that could hamper launching. This course is typically parallel to the wave fronts to reduce pitching motion. It should be noted that at no time is it necessary to anchor the SSS (as in similar McCann Bell type operations) because there are no cables or umbilicals attached between the SSS, the submersible or the SSC. This is a significant advantage in deep water or where subsea equipment such as flow lines can be fouled by anchors.

After floating off its cradle the NGS is taken in tow by the SSS through a recovery line which remains attached at this time and is connected to the recovery winch on the SSS. The SSS can then ensure the NGS is positioned close to the subsea chamber at which point a swimmer, supported by a rubber diver's boat, enters the water and disconnects the recovery line. The NGS is now free to dive.

Diving is achieved by venting air from the soft tanks and the NGS descends to near the seabed observing the approach of the latter on a downward looking sonar and checking the depth gauge. When the

bottom is seen to be clear the submersible sits gently down and scans the "horizon" with the search sonar until the reflection of the SSC is noted. The SSC reflection is displayed on a CRT giving range and bearing. The heading of the NGS is then set to close on the SSC and the thrusters are started to approach the target.

On arriving within visual range of the SSC the submersible rises to land the forward part of its skids on a small circular landing pad surrounding the docking ring of the SSC. By ballasting slightly heavy and moving slowly forward, the NGS slides over the landing pad with the projecting docking ring between the skids. Forward movement continues until a centrally located "stop" contacts the edge of the docking ring. At this point the NGS is centered correctly over the docking ring, being constrained on three sides by the two skids and the "stop". Visual observation of the latter stages of the approach can be made by means of a view port installed at an aft facing angle in the rear of the command chamber as well as through the view port placed in the center of the external hatch of the transfer chamber.

Having thus centered the NGS over the docking ring of the SSC the pilot starts dewatering pumps with suctions located in the docking skirt of the submersible and causes the NGS to "squat" down onto the docking ring by activating the hydraulic ram which compresses the suspension system of the skids.

A primary lip seal on the edge of the docking skirt draws the secondary seal rapidly down onto the docking ring because of the suction created by the dewatering pumps. Subsequent pumping further reduces the pressure between the NGS and the SSC until, when one atmosphere pressure is reached the outer hatch of the NGS "pops" due to equalization of pressures. Further pumping removes the remaining water trapped in the skirt area until men can stand on top of the SSC to open a hatch for access into the chamber.

Before opening the hatch into the SSC, samples are taken of the atmosphere in the SSC to check for hydrocarbons or other hazardous situations. When it is known that it is safe to enter the SSC the workmen first close the hatch between the transfer chamber and the command chamber. Next they don breathing gear and inert their atmosphere with a Freon based fire extinguishing gas after which the SSC hatch may be opened. Prior to entering the SSC additional inerting gas is fired into the SSC after which the workmen may descend to carry out their tasks.

On the return journey the workmen climb back into the transfer chamber closing hatches on the top of the SSC and the bottom of the NGS. The pilots then open valves to flood the skirt area and equalize pressures. This process can be speeded by injecting compressed air from the submersible's ballast system. When the pressure inside the skirt is equal to the ambient sea pressure the NSG rises off the landing pad and returns to the surface for recovery.

The NGS is recovered on board the SSS by reversing the launching process. The submersible is taken in tow and winched into the submerged cradle at the end of the ramp. NGS and cradle move together up the ramp to deck level. Elapsed time from landing on the cradle to recovery on deck is approximately one minute.

COMMERCIAL DIVER TRAINING

By

Mr. R. Landry
Seneca College of Applied Arts and Technology
King Campus

INTRODUCTION

It was as a consequence of the growing interest in the sea, its ecology and its resources, that Seneca College investigated the need for an intensive course to train industrial diving techniques. In preparation for what is now the Underwater Skills Program, an ad hoc advisory committee of professionals and experts from industry and government was assembled to guide the development of the program and to oversee its various aspects. At present, Underwater Skills is a two-semester program for commercial diving which trains students in the underwater skills required to work in rivers, lakes, canals, bays and oceans.

Graduates can be employed, nationally and internationally, for a variety of positions in marine construction, salvage and structural inspection. In addition, the increasing demands for oil and natural gas are creating jobs for divers on off-shore drilling rigs and with production teams developing new fields.

The first Underwater Skills class begun in September, 1973, graduated a modest fifteen students; whereas in 1977, thirty-four graduated. Of these, 90% were employed in the commercial diving industry.

What follows gives an overview as to the location of the course, admission requirements, fees, faculty, facilities, curriculum and timetable.

LOCATION

The Underwater Skills Diver Training Centre is located at the King Campus of Seneca College, approximately 30 miles north of Toronto, at King City, Ontario, Canada.

The campus, formally the T. Eaton Estate, is part of 696 acres of farm land and bush with a 16-acre, 50 ft. deep spring-fed lake in the centre.

Classes are held at various locations on the campus including a 60 ft x 30 ft enclosed diving barge on the lake, a 50,000 gallon 40 ft. deep diving tank with underwater windows in Garriock Hall, and a rigging/mechanics shop with three welding and burning tanks.

ADMISSION REQUIREMENTS

The general admissions requirement is successful completion of Grade 12 (Ontario Secondary School Graduation Diploma with 27 credits) or its equivalent.

Applicants who are 19 years of age or older and who do not have Ontario Grade 12 or its equivalent may be admitted directly into the course after pre-admission testing and enrol in academic upgrading of which the subject matter will be determined on an individual basis.

In addition, a candidate for diver training must meet the physical and psychological standards set down by the Underwater Skills Admissions Committee, be a certified sports S.C.U.B.A. diver, a competent swimmer, and successfully complete an O_2 and pressure tolerance test.

FEES

The fee for the Underwater Skills program is $180.00 per semester. This amount represents $162.50 for tuition and $17.50 for student activity fee, but does not include the cost of textbooks, special supplies, field trip costs, or laboratory fees of $25.00 per semester.

FACULTY AND STAFF

Each member of the Underwater Skills faculty has been specially selected for his particular background in the diving industry. The combined experience of these instructors includes every aspect of commercial and military diving.

CURRICULUM

The course of instruction has been carefully designed to offer the quality of training required for employment in the professional diving field. To this end, classes are kept small (maximum of 20) and emphasis is placed on rigid safety standards and applied expertise to develop not only competent divers but also well-rounded marine construction technicians. Each work project is designed to train and test the students' ability, resourcefulness and capability for practical achievement.

The two semesters are divided into three Modules of Instruction. Module I runs from July through August; Module II, September through December; and Module III, January through March. These Modules consist of 1120 hours of instruction, of which approximately 40% is classroom presentation and 60% applied activities.

In the field, the student is subjected to all of the climatic phases including sub-zero arctic-type environments and ice conditions.

Field excursions are conducted regularly to various marine construction locations in the Great Lakes area to offer students actual on-site training and experience.

Students are assessed and graded on both underwater and topside performance throughout the course. A grade of at least 80% in each subject is required for graduation. Habitual failure to comprehend orders, non-compliance with College regulations, panic, displays of temper or conduct impairing the safety of others are grounds for dismissal.

Physical fitness is emphasized and students must achieve a fitness level acceptable to international standards.

CURRICULUM TABLE OF CONTENTS

Module I (8 weeks)	Hrs/Wk Lecture	Hrs/Wk Practical	Hrs/Wk Total
DVT 111 Diving Theory	8	0	8
APD 111 Applied Diving	0	17	17
ASR 111 Applied Seamanship and Rigging	5	5	10
	13	22	35
Module II (14 weeks)			
CDT 121 Construction Diving Techniques	5	0	5
APMN 121 Applied Mechanics and Navigation	6	5	11
APD 122 Applied Diving	0	15	15
LH120 Report Writing	4	0	4
	15	20	35
Module III (10 weeks)			
ODT 131 Offshore Diving Techniques	5	0	5
DVS 131 Diving Systems	5	0	5
APD 133 Applied Diving	0	20	20
UWP 131 Applied U/W Photography	2	3	5
	12	23	35

FIELD TRIPS

Field trips are a regular and integral part of the curriculum. Numerous job sites are visited with the aid of a 22 ft trailable landing craft. Teams of students are exposed to actual field conditions and have the opportunity to inspect and observe construction projects and techniques previously discussed in class. Seamanship and navigation are put to the practical test aboard a 50 ft. tug.

CURRICULUM OBJECTIVES

Diving Theory III

To offer the student comprehensive instruction in diving physics, physiology, diving hazards, safety procedures, decompression and treatment table development and usage and the safe operation of hyperbaric chambers.

To emphasize the importance of group effort and co-operation.

To develop the personal discipline required for safe underwater operations and a respect for regulations and procedures.

Applied Diving III

To offer the student comprehensive practical and theoretical training in the care and use of various types of commercial diving equipment (masks, helmets, etc.) and to acquaint him with operational techniques used in the field. Emphasis will be placed on projects conducted in simulators and in actual field conditions.

To emphasize the importance of group effort and co-operation and to develop leadership.

To develop the personal discipline required for safe underwater operations and to acquire a respect for regulations and procedures. To develop safe operational procedures for tenders, divers and supervisors and to emphasize a diver's limitations in various jobs while acquiring self-confidence.

Applied Seamanship and Rigging III

To offer the student practical training in seamanship and topside rigging both for the marine industry and for small boat handling, care and maintenance.

To develop the personal discipline required for safe operation of various vessels and a respect for regulations and procedures at sea.

To learn the personnel responsibilities and the use of safety equipment as presented by the Construction Safety Association of Ontario.

Construction Diving Techniques 121

To examine marine structures both on and off shore with emphasis on the design and application of building materials for pipelines, pile structures, piers, bridges and dams. Also included will be the principles, designs and installations of the various types of oil exploration and production systems and related structures.

To develop the personal discipline required for safe operation of various construction projects and a respect for regulations and procedures.

Applied Diving 122

To offer the student practical training in the care and use of various types of commercial diving equipment and to acquaint him with the operational techniques used in the field. Emphasis will be placed on projects conducted in simulators and in actual field conditions.

To emphasize the importance of group effort and co-operation and to develop leadership.

To develop the personal discipline required for safe underwater operations and a respect for regulations and procedures. To develop safe operational procedures for tenders, divers and supervisors, and to emphasize a diver's limitations under various conditions while acquiring self-confidence.

LH 120 Report Writing

To learn how to write to get the idea across. To this end, the student will concentrate on four activities.

- separating idea development from the actual writing (i.e. the mechanical process from the creative process.
- analyzing each writing task in terms of its components. No matter how complicated, all technical writing assignments have recognizable forms.
- juggling the component parts of the Three-part Summary, the Process Description, and the Abstract to meet the specific objectives of report assignments.
- learning the basic formats in which the bulk of technical information is presented.

Applied Mechanics and Navigation 121

To learn how to use underwater tools and related systems found in the marine industry. Emphasis will be placed on the theory and application of submarine cutting, explosives, salvage techniques and tools. To learn coastal piloting and basic navigation.

To develop the personal discipline required for safe operations of various marine construction equipment and a respect for regulations and procedures.

Diving Systems 131

To familiarize the student with advanced diving principles and techniques including those used in mixed gas diving, and saturation and sub-saturation theories. Included in this subject will be familiarization with underwater electronics equipment, covering pinger locators, side-scan sonar, diver communications, closed circuit video and magnetometers.

To offer practical training in the care and use of various types of commercial diving equipment and to acquaint him with operational techniques used in the field. Emphasis will be placed on projects conducted in simulators and in actual field conditions.

To emphasize the importance of group effort and co-operation and to develop leadership.

To develop the personal discipline required for safe underwater operations and a respect for regulations and procedures. To develop safe operational procedures for tenders, divers and supervisors, and to emphasize a diver's limitations under various conditions while acquiring self-confidence.

Applied Underwater Photography 131

To learn the basics of camera design, operation and maintenance, identification and use of various films, basic dark room techniques, environmental conditions, various lighting techniques, underwater equipment and enclosures.

To develop the techniques required to produce acceptable black and white photographs for the purpose of reporting various underwater conditions and structures related to industrial diving.

Applied Diving 133

To offer the student practical training in the care and use of various types of commercial diving equipment and to acquaint him with the operational techniques used in the field. Emphasis will be placed on projects conducted in simulators and in actual field conditions.

To emphasize the importance of group effort and co-operation and to develop leadership development.

To develop the personal discipline required for safe underwater operations and a respect for regulations and procedures. To develop safe operational procedures for tenders, divers, and supervisors and to emphasize a diver's limitations under various conditions while acquiring self-confidence.

Off-Shore Diving Techniques 131

To examine the off-shore diving techniques and procedures used in the petroleum industry. Emphasis will be on the diver's role in support of exploration, production, and maintenance of the various systems related to this industry. To become familiar with the design and operation of the various structures required for off-shore petroleum exploration.

To develop the personal discipline required for safe operations in the off-shore petroleum industry.

TRAINING FACILITIES

The facilities have been designed for safe diver training while allowing maximum experience underwater. Seneca students have gained construction know-how in that they have helped to build many of the facilities presently in use.

Indoor Training Facility (Garriock Hall)

The 50,000 gallon, 40 ft. deep, indoor training tank offers the student maximum safety while gaining familiarity with commercial diving equipment and techniques. This 40 ft. long concrete pool facilitates underwater viewing through a 4 ft. x 3 ft. glass window.

Optimum water conditions are maintained to allow the student maximum visibility while gaining initial experience with diving equipment and tool packages, and fundamental knowledge of underwater tasks prior to the actual site conditions.

On the deck, there is a 54-inch diameter, double-lock hyperbaric chamber where students gain "hands-on" experience in the chamber techniques required for surface decompression and the treatment of diving accidents.

Lectures are carried out in well-lit, comfortable classrooms nearby.

Rigging Shop · Welding and Burning Facility

A fully equipped shop is located near Garriock Hall. In this facility students learn maintenance and repair procedures required for the various diving gear, compressors, generators, winches, and gas and diesel engines used in support of the course.

Adjacent to the rigging shop are three 18 ft. deep enclosed steel tanks. Students practice the techniques required for underwater electric burning and welding in a controlled environment. Instructors maintain a watchful eye through the various large glass ports located around the tanks.

The Diving Barge (Lake Seneca)

The 60 ft. x 30 ft. steel-hulled, catamaran-type barge can be moored at several locations thus duplicating the greatest number of typical on-the-job environments and tasks. It is designed for year-round operations with heated classroom, moon-pool, and indoor shop facilities. A 50 kw. generator supplies electrical power to the 100 CFM air-supply system, the lighting system, and for other systems requirements.

The open deck facilitates large projects, and two independent boom systems lower divers and equipment to the sites. The integrated HeO_2 console and gas storage area allows practical training in surface-supplied deep diving techniques.

On the barge, students learn:

1) open-water use of commercial diving equipment

2) underwater burning

3) how to use underwater power tools

4) valve, pipe, and fitting projects

5) salvage techniques

6) top-side and underwater rigging

7) concrete construction techniques

8) underwater photography and the use of video systems

9) how to work in turbid water and under ice.

CAREER OPPORTUNITIES

Upon successful completion of the Underwater Skills course, graduates can be employed as trainee divers and tenders in both the off-shore oil and marine construction industry. A background in seamanship and rigging qualifies graduates for placement with the various surface support teams.

Graduates have the opportunity to travel in the marine industry. Oil exploration and production requiring diving technicians is worldwide. Employment can be found in the North Sea, High Arctic, Persian Gulf or South Pacific. The coastal and Great Lakes regions of Canada offer placement for graduates working in the marine construction industry. Divers are required to install and maintain various underwater marine structures and pipelines. Diving companies operating in Lake Erie area employ graduates in support of natural gas exploration and production.

PLACEMENT STATISTICS

The majority of Underwater Skills graduates have been successful in attaining related employment in both the domestic and international marine industry. The following statistics represent placement for 1976-1977. Also included is a partial list of present employers.

	No. of Graduates	Total Available for Work	Related Work	Further Education	Other	Salary Range
1976	20	17	17	2	1	$10/16,000
1977	34	29	23	8	3	$12/13,000

Can-Dive Services
North Sea Services
B.I.X. International
Universal Enterprises
Canada Gunite
Alfonso Diving Services, St. John's (Newfoundland)
Great Lakes Marine Services
Turzillo Contracting
Underwater Gas Development
Sub-Sea International
Underwater Exploration
Young and Forbes
Oceaneering International
Master Diving Services
Ocean Systems
Deep Diving Systems
Leo Geiswinkler Diving Services
Forand Marine and Construction

OTHER MARINE COURSES OFFERED AT SENECA

The Finch Campus of Seneca College offers two day diploma programs related to the marine industry. Resources Engineering Technology Marine elective qualifies graduates in engineering involved in ocean and lake surveying, shoreline engineering, off-shore resource location and recovery, water supply structures, power plants design and measurement and control of polution in bodies of water.

This course includes most of the subjects included in the Resources Engineering Technology with the addition of subjects in oceanography, marine surveying and marine engineering.

The elective subjects cover such topics as hydrographic surveying, sounding, underwater sampling techniques, currents, shorelines, waves, erosion and deposition of material, special construction problems and design requirements.

Both practical and theoretical subjects are included in the curriculum enabling the graduates to become immediately valuable to an employer and also to grow with the rapidly advancing technology in this area.

The Civil Engineering Technology Marine elective course covers most of the subjects in the civil engineering technology course of study with additional topics in the fields of oceanography, marine surveying and marine engineering.

These will prepare the graduate to join the engineering team involved in design and construction in the growing areas of coastal engineering, off-shore exploration, and oil production, bridge and harbour engineering, water intake structures and power plant construction.

The elective subjects cover such topics as hydrographic surveying, sounding, underwater sampling techniques, currents, shorelines, waves, erosion and deposition of material, special construction problems and design requirements.

The subject material includes both theoretical and practical items enabling the graduate to become valuable members of the team immediately and to progress in a growing profession.

This course is fully accredited by the Ontario Association of Certified Engineering Technicians and Technologists (OACETT).

Both of the above courses are six semesters in duration.

FEDERAL FUNDING OF THE CANADIAN COMMERCIAL DIVING INDUSTRY AND STATUS OF A PROPOSED NATIONAL UNDERWATER CENTRE

BY

Mr. L.M. Edelstein

To digress slightly from the originally intended subject matter, my purpose is to advance my own perceptions of the current status of industry/government co-operation, the future of that relationship and an update of the proposed underwater centre.

Speaking to the latter point first, back in March, 1977 there was a discussion between Don Fitzpatrick, then of the Newfoundland Department of Industrial Development, and myself, concerning possible ocean-related provincial endeavours. The idea of a national facility for deep diver training, research, and development was discussed. Access to ice-covered, deep cold water, as well as proximity to expected Canadian offshore activity, were primary reasons for placement in Newfoundland. In order to determine follow-on course of action, a decision was made to bring together an ad hoc advisory committee from across Canada. Meeting in St. John's, the members recommended expansion of the idea from solely deep diving to all aspects of underwater training, research and development and testing. The suggestion was accepted and it was also resolved that a consultant or consultants would be hired to assess future domestic and global market requirements, technology trends, current underwater industry infrastructure in Canada, and regional socio-economic assessment of locating the facility in and near St. John's.

A primary caveat in the exercise has been, and will continue to be, recognition of existing underwater facilities now in Canada. That is, to incorporate such bodies as the DCIEM Deep Dive Facility into planning and utilization discussions revolving around the proposed centre.

During a quite recent trip to Europe, two nationally funded underwater institutes were visited: "Norwegian Underwater Institute" in Bergen and "Underwater Training Centre" in Fort William, Scotland. Both facilities fail to encompass all, or even most aspects of underwater training and development. General reaction through Europe (to the proposed Centre's aims) was quite favourable with definite indications that such an organization would be useful for European requirements and could easily tie in with other bodies in the ocean sector.

It is hoped to have assessment studies completed by early summer 1978. If the decision arising from study conclusions points to a positive requirement for an underwater centre, application for further funding will be made to provincial and federal sources. Overall, a time period of three years from funding requests to centre opening has been put forward as a "neighbourhood" figure. Flexibility is of premier importance in such a proposal as this, and so time tables at this juncture are sketchy at best.

Although a cost-benefit relationship must be part of the decision-making process vis-a-vis an underwater centre, two non-quantifiable factors need also be considered.

First, that Canadian requirements to operate below ice cover and in very cold and deep water could be satisfied in great measure through the training, testing, and research programs of the centre. Thus, reliance on non-Canadian expertise and technology would be kept to a minimum, and would go a long way in providing overall operational excellence in our Arctic and Labrador coast areas. The key, then, is industrial benefit to Canada.

Second, envisaged is the acceptance of non-Canadian nationals into the training and research programs. Where available, Canadian equipment would be used. The objective is to expose non-Canadians to the historically reliable, capable, and durable ocean industry products coming from Canada. It may very well be that upon return to their home countries, the individuals (who may in positions to recommend purchases or have that authority themselves), would be inclined to use the same Canadian-manufactured hardware in their own activities.

At present, then, the choice of consultants is being deliberated, and a formal advisory committee is to be formed by December.

Moving on to another discussion topic, rather than relate the funding and assistance available to the private sector (which can be obtained from regional offices or IT&C headquarters), I feel it more important for purposes of this forum to speak briefly about a few problembs faced by the Canadian underwater community.

Communication within the industry is far from ideal. As well, government/industry and government/government co-ordination has been fragmented and has functioned as a "brush fire" approach instead of a co-operative, defined, thought-out overall plan of action. Decisions have tended to be "knee-jerk", oftentimes not tied to any previous decisions.

The underwater community is, I believe, hampered by the geographic distances involved in communicating as well as lack of information exchange. There is no information disseminated through journals or newsletters, simply because no ocean industry association or forum exists. Suggestions for formation of such a body have come down for at least eight or nine years, but no individual or organization has acted to bring together the diverse elements of the industry sector. Ocean industry and/or underwater associations exist in many countries - U.S., U.K., Netherlands, Norway, Germany, Japan, France, etc. None exists in Canada. It seems strange that in a community where individuals certainly know one another, and hearsay regarding everyone's activities runs rampant hard corporate data, non-confidential in nature, does not interchange from firm to firm and person to person. Egos ride herd over the potential of the sector. Unless someone in the private or academic sector takes the bull by the horns and makes a serious attempt at initiating an underwater or ocean industry association, progress will be slow and success limited to the largest companies with the most resources. Medium and smaller companies will remain pretty much as they are, almost fighting for their very existence.

If the industry can speak with one voice, government will surely listen more closely, and participation in offshore projects more likely and more meaningful.

On the same subject of industry talking to government, the pattern has been almost without exception, where we in Ottawa hear only about requests for money or situations where foreign operators may be impinging on Canadian "full and fair participation" in ocean-related programs. Few efforts are made to keep Ottawa abreast of industry R&D and of industrial participation in activities. Were this the rule (rather than the exception), I venture to say that we could do more to help industry through planning and anticipatory programs - not by reacting to crises which occurred "yesterday". I would recommend that industry speak with Ottawa more often, even if it is only to report that activity is uneventful. Perhaps we may know of requirements and tenders which slipped by a company unnoticed. Certainly we should be given an opportunity to function more effectively. I would say that we "feds" in the oceans side of things are a bit different from the average bureaucrat, and would tend to react in a manner unlike our brethren; that is, with an eye towards getting industry input for our decisions, and trying to maximize industrial benefits.

It is likewise vital for the many government bodies concerned with oceans affairs to interact with each other, communicate with each other, and make honest attempts to end the duplicate efforts and cross-purposes. Committees are likely not the answer - personal contacts and informal gatherings may be more suitable.

Finally, we need to speak in a unified manner vis-a-vis "full and fair opportunity" for our ocean industry in our waters. This concept is not unique, as many, many countries now espouse the same edict - either in legislation or by informal "verbalization". By promoting the same idea we are simply following the lead of the U.S. and Western Europe. We are not advocating protectionism or raising non-tariff barriers. We are simply asking for industrial benefits for our industry during the extraction of our resources from our territory. Anyone who opposes this approach is tacitly approving further incursions by foreign companies into our offshore, without seeking benefits for Canadians and Canada.

For the future, I would hope that government and industry can work more closely together. I will do all I can to acquaint the other segments of government with the underwater requirements of Canada and with the potential benefits to Canada from a stronger underwater industry sector.

I ask that industry assist me in this venture and allow me to act as a civil servant in the truest sense of the term.

A NATIONAL PROGRAM FOR MANNED UNDERWATER WORK

By

Joseph B. MacInnis, CM,MD,FRGS

The following is an edited version of the author's remarks. It is his belief that brevity is a catalyst of action.

Manned undersea exploration and underwater work are low on the list of national priorities. The Canadian government is concerned with far more serious issues - environmental pollution, unemployment, inflation, new energy sources - to name only a few. Even within the National Ocean Policy of 1973, manned underwater work merits only indirect reference; it is contained in the statement "that within five years Canada achieve an internationally recognized ability to operate above and below arctic ice".

However, all of you have attended this meeting because you strongly believe in the importance of diving and manned underwater work. You see it as a great challenge, either for industrial, military, or scientific reasons. For those of us who have been involved in diving for a significant time, it is a challenge of the spirit as much as it is a challenge of technologies.

All of you represent the Canadian diving community, from St. John's to Vancouver. You are well aware of the over 100 industrial, scientific and military tasks that are being carried out underwater in this country and abroad, and you are even more aware of the direct benefits of such work. For the industrial diver, it is accomplishment of a task and the making of a profit. For the scientific diver, it is understanding the processes of the ocean and the human complexities of diving. For the military diver, it is the ability to carry out surveillance and control of our continental shelves. And we should not forget the recreational diver. There are over 50,000 of them in Canada and they represent enthusiasm and a pool of talent.

For many of you it is the indirect benefits of diving that are important. Among these are friendship, critical thinking, shared adventure and the value of achievement. These are intangible, but of great significance.

Of the almost 100 of you who have come to this meeting, there is great strength in your diversity. Among you are physiologists, engineers, doctors, students and businessmen, all sharing a genuine love of the sea and your ability to work beneath it. You come from all walks of life and every part of the dominion. But until now, your activities have been carried out in a highly random fashion. Not only are your efforts geographically scattered, from the east to the west coast and up into the Arctic, but there is no overall theme, no effort to coordinate the importance of what you do. You have need for a unified voice.

There are many major issues coming up on the horizon for the Canadian diving community. Some of them are:

a. future directions for research and development - in the laboratory and in the sea;

b. a need to improve our capacity to work deep in cold water;

c. search and rescue for submersibles and divers, particularly in polar waters;

d. future safety and training programs.

This is only a partial list, a hint of the size of the problem.

If there is to be a national program for manned underwater work in Canada, its design and presentation will have to come from the diving community itself. The government will not do it for you--but it will listen carefully to what you have to say.

It is imperative that in the near future the diving community sit down and conceive a series of objectives, strategies and programs that will enhance the safety and effectiveness of working divers on our deep continental shelves.

A logical place for this effort to begin is here at DCIEM. Here, in the geographic centre of the country, is the facility and staff to provide a focal point to become "a centre of excellence". What is needed is the vision. And the follow-through.

A start has been made. But only a start. This is the second diving symposium held here at DCIEM. But, it is the long empty interval between these symposia that really should concern you. Nothing really happens. No coordination. No coherent objectives. No newsletters. No shared industry, military and scientific programs.

We can look elsewhere for possibly helpful precedents. One of these is a Manned Undersea Science and Technology (MUST) office that operates under NOAA in Washington. It coordinates scientific diving programs in the United States and works very closely with the U.S. Navy. Because of the relatively small size of your constituency here in Canada, it should be far easier for you to coordinate your efforts.

Today's diving community is, as Coldridge put it in his poem, "The Ancient Mariner", "... as idle as a painted ship upon a painted sea". The problem with this particular ship is that it is not only idle, but that it has no compass nor a set of charts to tell it where it should head. Without immediate action, taken together, the Canadian diving community will find itself headed serenely for some uncharted reef. The time for action is now.

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